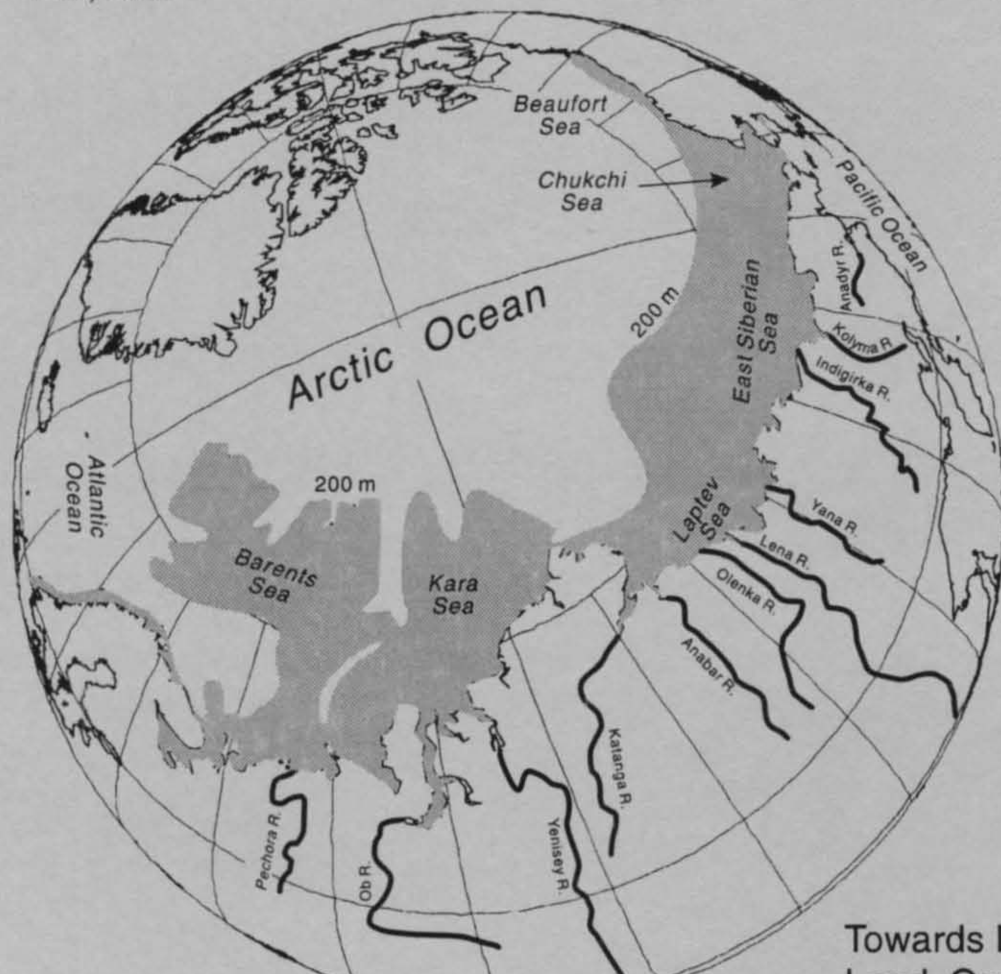
Reports of National Science Foundation, Arctic System Science Sponsored Workshops to Define Research Priorities for Eurasian Arctic Land-Shelf Systems

Workshops held at:

Byrd Polar Research Center
The Ohio State University,
Columbus, Ohio
January 12th - 14th, 1995

Texas A & M University
Arlington, Virginia
October 16 - 17th, 1995

Arctic & Antarctic Research Institute
St. Petersburg, Russia
November 6 - 8th, 1995



Towards Integrating Land, Ocean and Paleoenvironmental and Human Dimension Components of ARCSS

Editors: Steven L. Forman and G. Leonard Johnson

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FOREWORD

One of the last remaining frontiers in polar science is understanding the interactions between the broad, shallow shelf-seas and Eurasian-continental hydrologic system that span the gateways to the Arctic Ocean. In recognition of the importance of the Eurasian Arctic in influencing and responding to climate change a series of workshops were held to define research directions of mutual interest between North American and former Soviet Union colleagues. This publication contains summaries of three National Science Foundation, Arctic System Science supported workshops held in 1995. The initial workshop, held in Columbus, Ohio in January, 1995, provided a wealth of insight to formulate both broad and specific research questions. A subsequent follow-up workshop in Arlington, Virginia provided additional definition on research strategies. The final workshop, organized by Russian colleagues at the Arctic and Antarctic Research Institute, St. Petersburg, Russia in November, 1995, provides a perspective on research priorites of former Soviet Union collegues.

The first report in this volume of the Columbus workshop, was previously presented (BPRC Misc. Report # 327). We have decided to re-issue this report with subsequent workshop reports because the Columbus report was often the "meter" to stimulate ensuing discussions.

An important premise in organizing these workshops was to integrate process, paleo-studies, and human dimension approaches within the context of understanding environmental change, the broader response of the climate system and the ultimate effect on the human condition. This approach provided diverse input from a broad spectrum of Arctic scientists from both sides of the Atlantic Ocean. The concensus reached from these workshop provides a wealth insights to eventually establish a Russian-American initiative on shelf-land environments in the Arctic.

Report of "EURASIAN ARCTIC LAND-SHELF SYSTEM: Columbus Workshop"

held at Byrd Polar Research Center
The Ohio State University
Columbus, Ohio
January 12th-14th, 1995

Workshop Report Editors: Steven L. Forman and G. Leonard Johnson

EXECUTIVE SUMMARY

A workshop, with over forty biological, physical and social scientists from Russia, Latvia, the U.S., Canada, Norway and Germany attending (Appendix 1), was held at the Byrd Polar Research Center, January 12th to 14th, 1995 to evaluate "Research Priorities for Russian Arctic Land-Shelf Systems." The focus of this workshop was to elucidate major oceanographic, terrestrial, and atmospheric parameters that presently control, and in the past 20,000 years altered the distribution of biota, sea-ice, permafrost, glaciers, and river discharge. The ultimate goal of the workshop was to identify new research directions that will improve boundary conditions for climate models, give added insight into the role of the Arctic in the climate system and delimit better the effects of Arctic environmental change on the human condition. Workshop discussion groups concentrated on defining major research questions for four broad topics: 1) Flux of sediment, water, and ice; 2) Biogeochemical cycling and ecosystem dynamics; 3) Cryospheric interactions; and 4) Human and biotic evolution. Discourse emphasized the driving physical processes, the subsequent biotic responses and hemispheric and global effects on the climate system. Below is a summary of the critical research questions culled by the discussion groups.

Water, ice, and sediment flux

The continental shelf of northern Eurasia is a controlling area for the flux of fresh water, ice, and sediments into the Arctic. More insight is needed on the current fluxes from Siberian rivers and associated effects on sea ice generation and circulation in the Arctic Ocean basin. There is compelling evidence that Holocene sea ice extremes exceeded historic variability and warrant further inquiry. Accurate representation of sea ice extent is essential for realistic parameterization of heat fluxes for modeling past and future climates. Below are the consensus research questions:

1. What is the interannual variability of Siberian river discharge and concomitant controls on coastal erosion, sea ice production, sediment, and nutrient fluxes into the Arctic Ocean basin?

2.What are the effects of fresh water input from northern Eurasia on stratification of the Arctic Ocean and global thermohaline circulation?

3. How has the land-shelf system responded to variable environmental/climatic conditions during the last deglaciation and the Holocene? Does the paleorecord provide an assessment of the direction and magnitude of potential environmental responses with future climate change?

Biogeochemical cycling and ecosystem dynamics

The source and fate of nutrients from Eurasian watersheds to Russian shelf seas and pan-arctic transport is poorly known. It is recognized that the three Russian rivers with the largest discharge, the Ob, Yenisei, and Lena Rivers are important for focussing nutrients and contaminants from broad areas of northern Eurasia into the Arctic. However, other drainages with a magnitude less discharge equally influence shelf processes. Questions remain as to the interannual variability of river discharge, nutrient availability and sequestering in estuaries, sea-ice extent, and shelf productivity. There is a clear need to obtain a greater understanding of shelf productivity and biodiversity with an ameliorated climate, perhaps similar to conditions during the early Holocene. The biogeochemistry and ecosystems dynamic group discussion distilled two major research questions.

1. What are the effects of altered climate to biodiversity, landscape evolution, and ecosystem dynamics on land and water?

2. What are the effects of altered run-off to the biological productivity and nutrient cycling on the Arctic Shelf?

Cryospheric interactions

Large uncertainties remain on the extent, configuration, and deglacial history of the last ice sheet to cover the Barents and Kara Seas. A larger discrepancy exists in the East Siberian Sea for the last glaciation, where field evidence indicates non-glaciation, models reconstruct a >1000 m thick ice sheet. Linked to a better understanding of the spatial extent of past glaciations is assessing the balance between isostasy and eustasy on the Russian continental shelf, which is presently an important control of coastal erosion. More insight is critically needed of dramatic changes in glacier coverage, permafrost stability and coastal geometry since deglaciation, particularly for the period of inferred rapid warming during the early Holocene. Future research on cryosphere interactions in the Russian Arctic should focus on addressing these broad questions:

1. How have the dynamics of the cryosphere of the Russian Arctic both responded to and driven climate change on different time scales and, based on an improved understanding of these processes, can we develop better predictive models for future change?

2. What controls the geographic differences in environmental response across northern Eurasia during the last 20,000 years, and what are feedbacks and linkages within the global climate system?

Prehistoric and historic human-environmental interactions

No place on earth is so little known about the history of human adaptations than in northern Eurasia. This region was largely ice free during the late Quaternary, served as a refugia for ice-age biota in the Holocene, and a staging area for the dispersal of humans into the Americas. Northern Eurasia and Beringia are key areas for resource procurement for past and present societies and offers an unique perspective on long-term human responses to climate change. In comparison to Beringia, the Russian Arctic contains a long history of human occupation, spanning at least the past 40,000 years. Today, there are a number of indigenous societies practicing traditional lifeways, providing continuity with past cultures. The most salient research questions are:

1. What environmental changes and/or cultural adaptations facilitated the migration of humans across northern Eurasia to the Americas?

2. How have indigenous populations adapted to changes in resource availability and environmental change?

3. How has the human factor affected the natural evolution of the Arctic and the global system? and What are the potential cultural strategies for future climate change?

An overriding consensus was the importance of fresh water input via Siberian rivers for density stratification of the Arctic Ocean, formation of sea ice, and latitudinal oceanic heat flux. Workshop participants underscored the primacy of the Arctic in modulating Earth's climate by changes in albedo and controls on oceanic thermohaline circulation. Of equal significance is the effect of past and future rise in sea level on the rate of coastal erosion and permafrost degradation. Deltaic and estuarine systems were recognized to integrate continental scale biogeochemical processes that deliver productivity-limiting nutrients and contaminants to Arctic shelves for pan-arctic dissemination. An unanimous assessment was the need to integrate existing data from the Russian Arctic and to develop stronger, and mutually beneficial scientific partnerships with Russian colleagues. Participants recognized the need to share basic data and environmental insights with native residents of Arctic Russia and northern Alaska.

FOREWORD

The recently improved access to the vast polar seas and lands of Russia provides unparalleled opportunities to heighten understanding of Arctic environmental processes and events. However, there has been little coordination within the North American scientific community and with Russian and European colleagues on defining research priorities in the Russian half hemisphere of the Arctic. Thus, a workshop sponsored by Arctic System Science Program of the National Science Foundation entitled "Research Priorities for Russian Arctic Land-Shelf Systems" was convened at The Byrd Polar Research Center, The Ohio State University, Columbus, Ohio on January 12th to 14th, 1995. The workshop was attended by approximately forty biological, physical and social scientists from institutions in Russia, Latvia, the U.S., Canada, Germany, and Norway (Appendix 1). The focus of this workshop was on defining interdisciplinary and circumarctic research priorities to elucidate land/shelf interactions from the present to the late Quaternary, emphasizing the past 20,000 years. An overriding interest is to elucidate major oceanographic, terrestrial, and atmospheric parameters that presently control and in the past altered the distribution of biota, sea-ice, permafrost, glaciers, and river discharge. The ultimate goal of the workshop is to identify new research directions that will improve boundary conditions for climate models, give added insight into the role of the Arctic in the climate system and delimit better the effects of Arctic environmental change on the human condition. Workshop discourse concentrated on defining major research questions for four broad topics: 1) Flux of sediment, water and ice; 2) Biogeochemical cycling and ecosystem dynamics; 3) Cryospheric interactions; and 4) Human and biotic evolution.

This workshop serves to complement existing scientific goals of Land-Ocean and Ocean-Atmosphere Interactions initiatives of ARCSS by linking the multitude of processes operating at the land-ocean interface, the continental shelf (Fig. 1). Consideration of paleoenvironmental records in northern Eurasia broadens the scope of paleoclimatic inquiry beyond the purview of the Greenland Ice Sheet Program (GISP II) and Paleoclimate of Arctic Lakes and Estuaries (PALE) program. This workshop aided in the integration of existing ARCSS programs by stressing the continuity between contemporary arctic processes and environmental assessment derived from the paleorecord.

The workshop report is a community effort, with much of the concepts, and text supplied by participants during and after the workshop. We are particularly in debt to the chairs and co-chairs of the discussion groups, R. Cranston, S. Pfirman, T. Goebel, W. Fitzhugh, D. Walker, W. Oechel, J. Brigham-Grette and S. Ishman for their written input. Approximately 70 copies of a preliminary draft of the workshop report were circulated for comment to attenders and other interested individuals. The report was modified inlight of fifteen reviews. This iterative framing of science priorities provides a full horizon of science opportunities for a potential Russian-American Arctic program.

We thank Lynn Lay for assisting with arrangements for the workshop and providing unlimited access to the Goldthwaite Polar Library. Gratitude is extended to Lynn Tipton-Everett for her significant efforts in editing the workshop abstract volume. We also thank John Nagy for his ideas and skill in preparing figures.

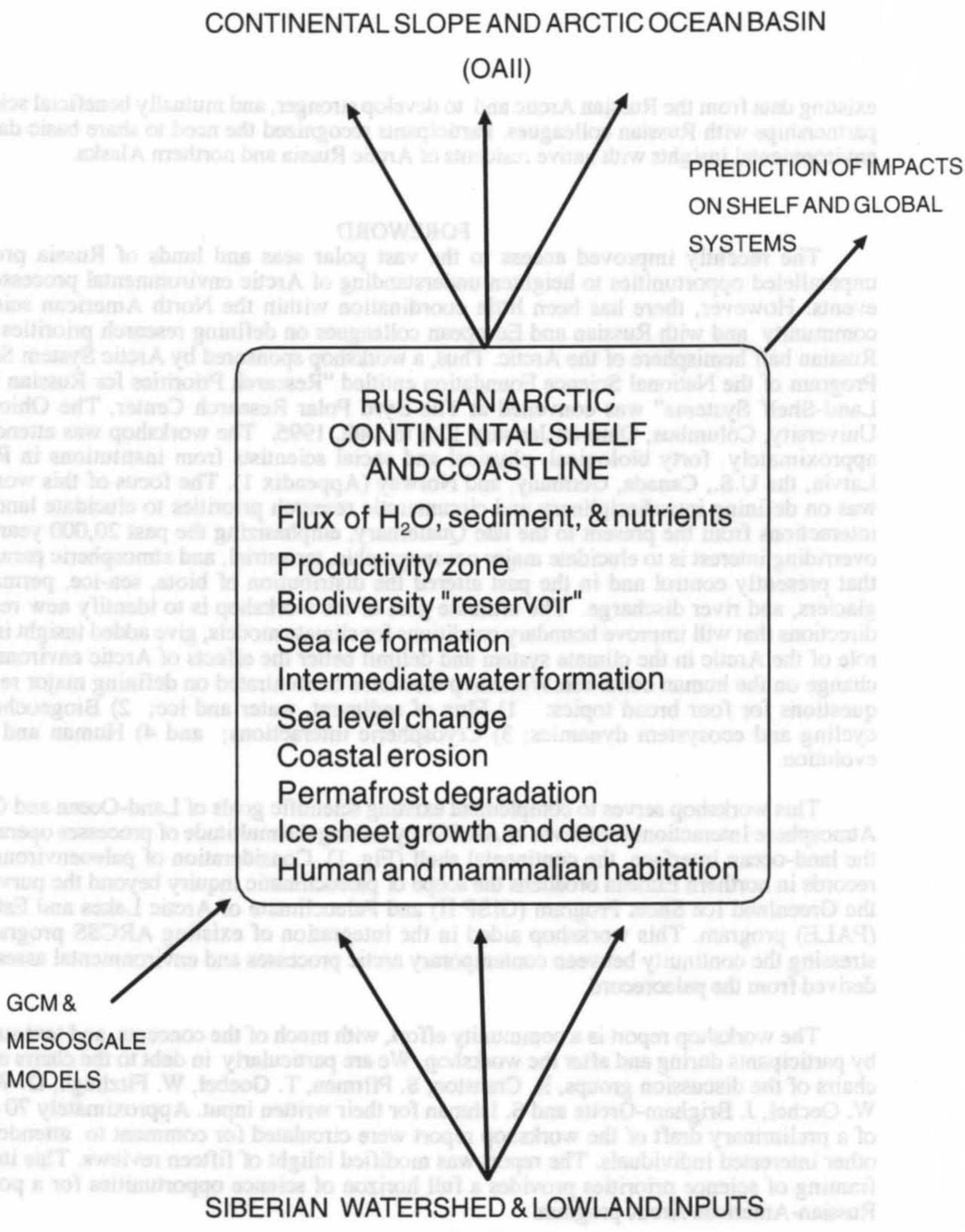

Figure 1: Linkages between land and ocean ARCSS components and Russian Arctic continental shelf and coastal processes and events.

BACKGROUND: RUSSIAN ARCTIC LAND-SHELF SYSTEM

The broad continental shelves of the Russian Arctic, spanning from the Atlantic to Pacific Oceans and fringed by the Arctic Ocean are critical areas for the flux of water and ice that modulate Earth's climate (Fig. 2). Our understanding of the climatic links between the cryosphere, atmosphere, and oceans is hampered because of an incomplete knowledge of ocean circulation, sea level changes, glacier extent, fluvial discharge and ecosystem response in the Russian Arctic. Basic environmental data on the configuration of past ice sheets, distribution of sea ice, course and discharge of rivers are needed to constrain predictions of global sea level (Peltier, 1988), ice sheet models (Lambeck et al., 1990; Peltier, 1994), boundary conditions for general circulation models (Kutzbach and Guetter, 1986) and to evaluate migration and evolution of biota in the northern hemisphere (Mochanov, 1993; Vartanyan et al., 1993).

Northern seas are a critical area for the ventilation of the global ocean (Bryan, 1986). The Norwegian/Greenland Sea and the seas of Arctic Eurasia are the Northern Hemisphere source of deep water from the cooling of saline North Atlantic surface-waters and ejection of brines with sea ice formation (Carmack, 1990 and references within). The influx of North Atlantic waters is an important, but ill-defined control on the extent of sea ice, poleward heat flux, and the concomitant distribution of precipitation in the Arctic. The advection of North Atlantic waters into the Arctic is linked to the hydrologic balance of the Arctic Ocean and adjacent continental shelf (Fig. 3). The inflow of Pacific waters through the Bering Strait, the outflow of intermediate and deep water from the Arctic Ocean, and the fresh water input from Siberian rivers can strongly influence the advection of Atlantic waters into northern seas (Reason and Power, 1994). The advection of Pacific and Atlantic waters is a dominant controlling factor of climate and habitability in the Arctic.

The shallow continental shelf seas of the Russian Arctic are sensitive to changes in sea level, particularly during glacial/interglacial transitions. Epicontinental seas of the Russian Arctic largely did not exist during the last glacial maximum, with ice sheets occupying the Barents and Kara Seas, and terrestrial exposure of most of the shelf beneath the Laptev, East Siberian, and Chukchi Seas with a ~ 120m fall in global sea-level (Fairbanks, 1989). Thus, many of the processes unique to the present shelf environment, such as sea-ice formation and concomitant brine ejection, were not fully operative during glacial periods. The Laptev, East Siberian and Chukchi Seas are particularly sensitive to post-glacial sea level rise, with much of the shelf area lying above 100 m water depth. Although, there is considerable uncertainty of the effects and magnitude of global warming, tide gauge records and models concur that global sea-level is rising at 1 to 2.4 mm/yr (Barnett, 1990; Gorniz and Lebedeff, 1987; Peltier and Tushingham, 1989). Future sea level rise may accelerate already rapid rates of coastal retreat of 1 to 10 m/year for many Arctic shelf coastlines (Reimnitz et al., 1994; S. Soloman, L. Timokov and E. Reimnitz, personnel communication).

The Arctic atmosphere has some of the highest concentrations of greenhouse gases on the globe reflecting the proximity to industrial output and large natural sources (Watson et al., 1990). In turn, Arctic ecosystems are particularly vulnerable to climate change due to the large carbon stocks in soils and the predominance of permafrost. Northern landscapes, though comprising 14% of the global land area, contain 25% of the global soil-carbon pool (Oechel and Vourlitis, 1994). The degradation of permafrost and the drying of soils may lead to new sources of greenhouse gases. Recent insitu measurements of gases evolved from tundra in northern Alaskan indicate that the tundra may be a source of CO_2 (Oechel et al., 1993).

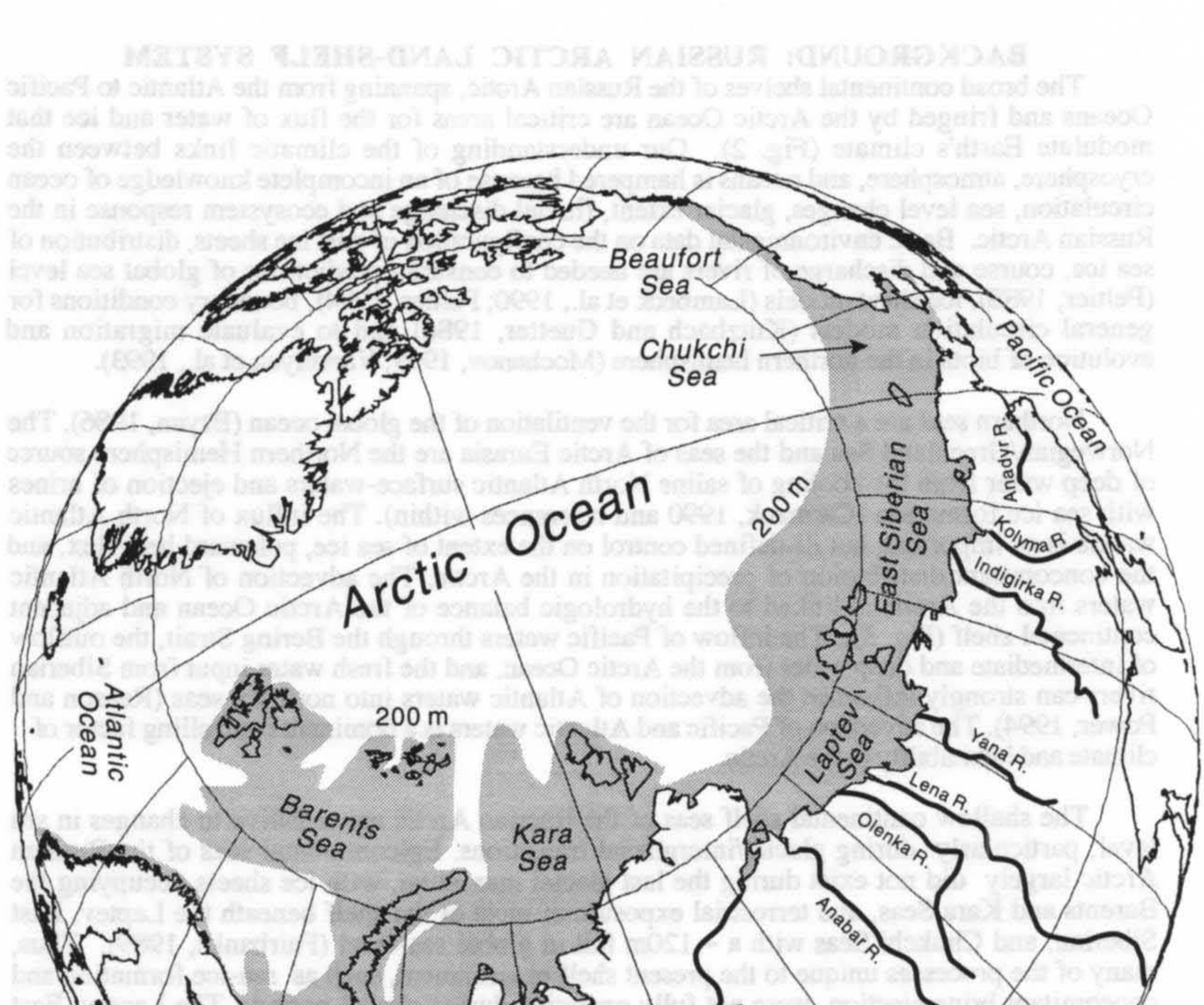

Figure 2: Continental shelf seas of the Russian Arctic. Shaded area denotes approximate area of water depth <200m.

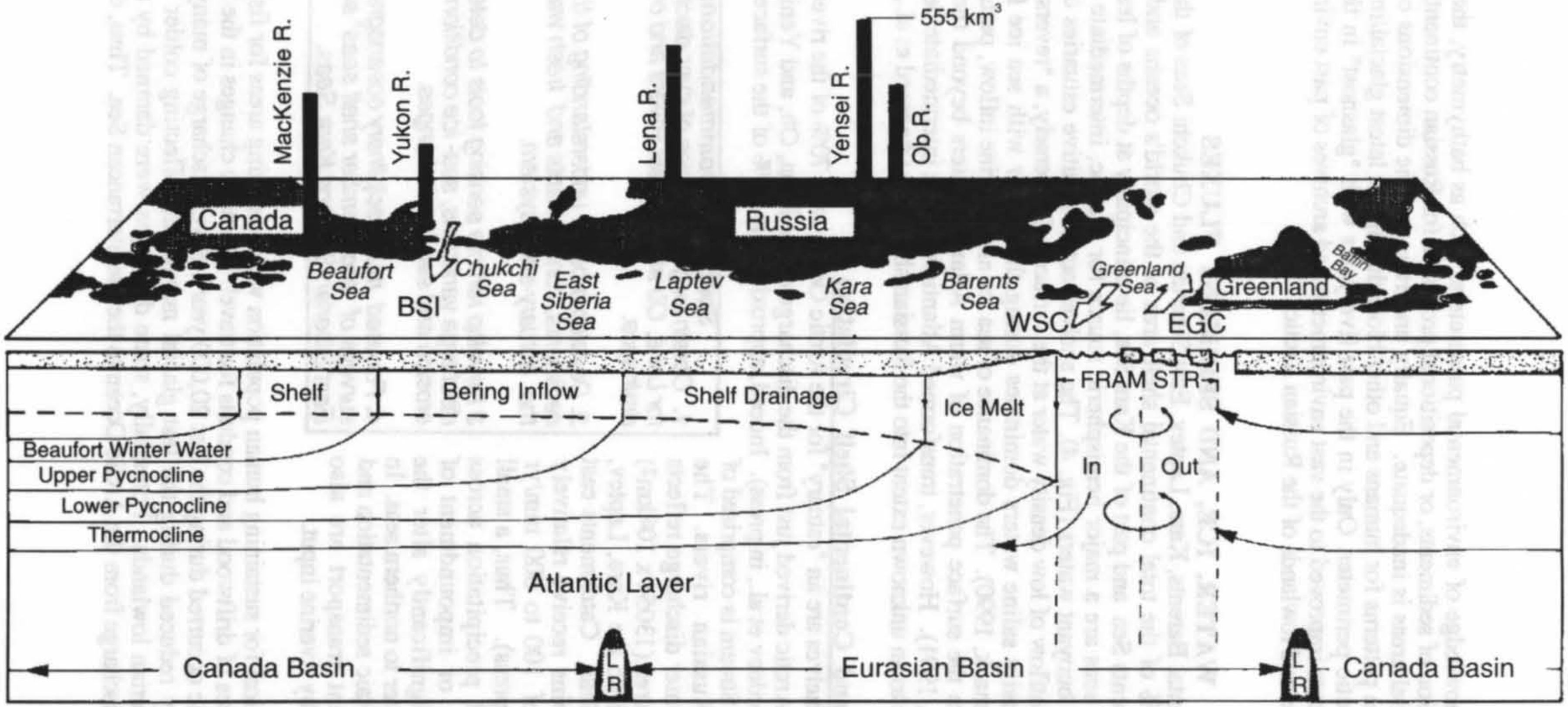

Figure 3: Schematic drawing of circulation and stratification patterns association with river inflow and halocline ventilation in the Arctic Ocean (modified from Carmack, 1990). Shown is river runoff scaled to average annual discharge of 555 km^3 of the Yenisei River.

Our current knowledge of environmental parameters, such as bathymetry, the sources, fluxes, and composition of sediments, or depositional processes for Russian continental shelves and adjacent terrestrial areas is inadequate. Equally uncertain are the dimensions of past ice sheets, and habitation patterns for humans and other biota during the latest glacial/interglacial cycle around the Arctic perimeter. Only in the past five years with "glasnost" in the former Soviet Union has access improved to the vast environments and archives of past environmental change on the shelves and lowlands of the Russian Arctic.

WATER, ICE, AND SEDIMENT FLUXES

The epicontinental Barents, Kara, Laptev, East Siberian and Chukchi Seas of the Russian Arctic comprise 25% of the total continental shelf area of the world's oceans and with the exception of the Barents Sea and part of the Kara Sea, lie principally at depths of less than 50 meters. These shelf seas are a major hemispheric source for sea ice, intermediate and deep waters, and riverine buoyant waters (Fig. 4). The shelves act as positive estuaries during the summer with a net outflow of low density water at the surface. Conversely, a "reverse estuary" outflow of high-density saline waters dominates during the winter with sea ice formation (Midttun, 1985; Carmack, 1990). The dominance of sea ice and riverine inflow, particularly in the summer, inhibits the surface penetration of warm Atlantic waters beyond the northern Barents Sea (Loeng, 1991). However, transformed Atlantic water at intermediate depths (150 to 400 m) penetrates to an unknown extent into the Russian shelf seas (Aagaard et al., 1985).

River Discharge and Continental Shelf Circulation

The Russian shelves are an "estuary" for the Arctic Ocean with 70% of the riverine (2960 km^3) input into the Arctic derived just from the discharge of the Lena, Ob, and Yenisei Rivers (Carmack, 1990; Gordeev et al., in press). Indeed, approximately 10% of the surface waters in the Transpolar Drift Stream is comprised of discharge from Russian rivers. The voluminous fresh water discharge reflects the large catchment area (13054×10^6 km^2) for rivers draining into the Kara, Laptev, and East Siberian Seas. Catchments east of the Ural Mountains receive relatively low precipitation of 100 to 600 mm/yr (Gordeev et al., in press). Thus, a small change in regional precipitation across continental Russia or impoundment of drainages could significantly alter the delivery of fresh water to northern seas. In turn, littoral and deltaic sedimentation and cross-shelf sediment transport are also strongly influenced by riverine input.

Specific Recommendations

1. *Obtain long time series of river discharge data for Lena, Ob and Yenisei Rivers and other drainages.*

2. *Develop a better understanding of the fate of sediments, contaminants and fresh water in the estuary-shelf system.*

3 *Develop remote sensing tools to detect river discharge variations, sea- ice conditions, coastal erosion and sea-level changes.*

4. *Focused multidisciplinary oceanographic surveys of "end member shelf seas" such as the East Siberian Sea and Kara Seas.*

Rivers are critical for sustaining human population with spawning areas for fisheries and sea mammals, sources of driftwood and conduits for travel. Dramatic changes in the hydrology of the Russian Arctic occurred during the last 20,000 years. River discharge of many Eurasian rivers was probably reduced during the last glacial maximum reflecting colder and dryer climates of the Siberian lowlands. Potentially, some drainages were damned by advancing glaciers, diverting discharge from the Arctic Ocean to the Mediterranean Sea. Thus, during the

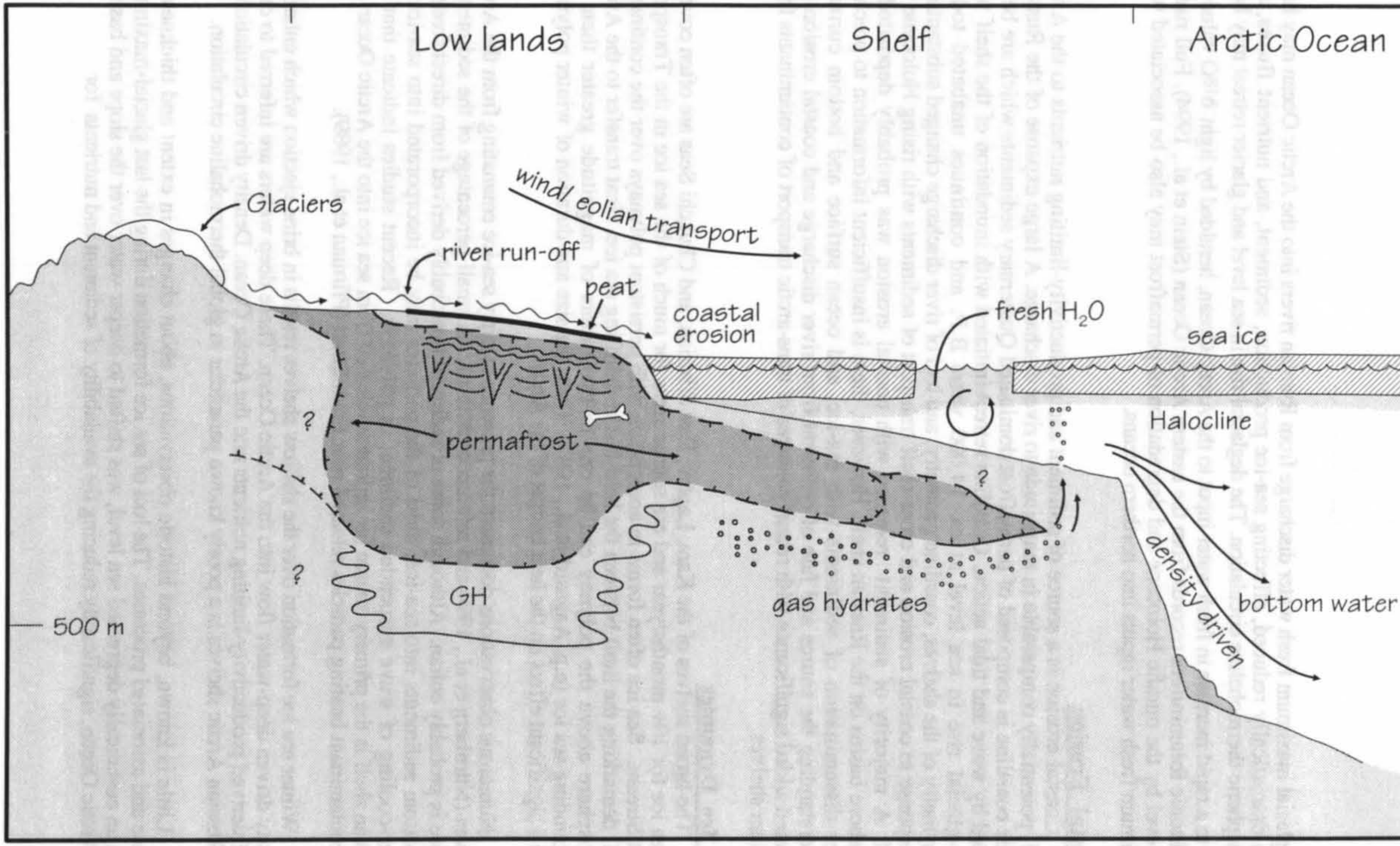

Figure 4: Schematic representation of processes operative in the Russian Continental Shelf and adjacent terrestrial areas.

last-glacial maximum fresh water discharge from Russian rivers into the Arctic Ocean may have been dramatically reduced, affecting sea-ice production, sediment, and nutrient fluxes, and hemispheric thermohaline circulation. The deglacial rise in sea level and glacier retreat may have lead to a rapid increase in fresh water input to the Arctic Ocean, heralded by light $\delta^{18}O$ values in planktonic foraminifera records from the eastern Arctic Ocean (Stein et al., 1994). Full rise in sea level by the middle Holocene and degradation of permafrost may also be associated with maximum fresh water inputs into northern oceans.

Coastal Erosion

Coastal erosion is a source of sediment and productivity-limiting nutrients to the Arctic shelf, potentially comparable in magnitude to river discharge. A large expanse of the Russian Arctic coastline is composed of permafrost dominated Quaternary sediments which are being eroded by wave and tidal action. Coastline retreat initiated with inundation of the shelf with post-glacial rise in sea level at ca. 14,000 years B.P. and continues unabated today. Bathymetry of the shelves, coastline geometry, and loci of river discharge changed substantially in response to coastal erosion and cross-shelf transport of sediments with rising Holocene sea level. A majority of sediment released with coastal erosion was probably deposited in nearshore basins on the Russian shelf. However, there is insufficient information to preclude wider dissemination of sediments with sea-ice, and ocean surface and bottom currents. Understanding the source and fate of sediment from river discharge and coastal erosion has assumed added significance with recent concerns of trans-arctic transport of contaminants from Russian shelves.

Sea Ice Dynamics

The broad shelves of the Kara, Laptev, East Siberian, and Chukchi Seas are often covered by sea ice for 10+ months/year and are source areas for much of the sea ice in the Transpolar Drift Stream. Sea ice often forms in association with persistent polynays over the continental shelf, demarking the limit between the land-fast and drifting sea ice. Heat transfer to the Arctic atmosphere above the polynay can be one to two orders of magnitude greater than the surrounding sea ice (e.g. Aagaard et al., 1987). Thus, the size and duration of winter polynays have a significant effect on the heat budget of the Arctic.

Numerous observations document the presence of dirty sea-ice emanating from the Arctic shelves (Nürnberg et al., 1994 and references within). A small percentage of the sediment in sea ice is probably eolian. Although some of sediment is probably derived from direct freezing of bottom sediments into sea-ice, most of the particles may be incorporated into sea-ice by super-cooling of wave suspended sediment in polynays. Recent studies indicate that the Russian shelf is the primary source for sediment released from sea ice into the Arctic Ocean and for contaminant bearing particles released near Fram Strait (Pfirman et al., 1989).

Winter sea ice formation over the shallow shelves results in brine ejection which enhances density driven deep-water flow into the Arctic Ocean. These deep waters are inferred to carry shelf derived productivity-limiting nutrients into the Arctic Ocean. Density driven circulation on the Russian Arctic shelves is a poorly known parameter in global thermohaline circulation.

Little is known, beyond historic observations, about changes in extent and thickness of sea ice and associated processes. The loci of sea ice formation during the last glacial-maximum, with an eustatically depressed sea level, was shifted to deeper water over the slope and basin of the Arctic Ocean, significantly reducing the availability of sediment and nutrients for entrainment. Sediment records from the Arctic Ocean during the last glacial maximum document a near cessation in sedimentation and dramatically reduced productivity, possibly reflecting greater sea-ice thickness and a less mobile pack (Stein et al., 1994; Jones, 1994a). The

WATER, ICE AND SEDIMENT FLUX RESEARCH PRIORITIES

The continental shelf of northern Eurasia is a controlling area for the flux of fresh water, ice, and sediments in to the Arctic. More insight is needed on the current fluxes from Siberian rivers and associated effects on sea-ice generation and circulation in the Arctic Ocean. There is compelling evidence that Holocene sea ice extremes exceeded historic variability and warrant further inquiry. Accurate representation of sea ice extent is essential for realistic parameterization of heat fluxes for modeling past and future climates. Enumerated below are research priorities to gain insights into water, ice, and sediment fluxes from the Russian Arctic.

1. What is the interannual variability of Siberian river discharge and concomitant controls on coastal erosion, sea ice production, sediment and nutrient fluxes into the Arctic Ocean?

2. What are the effects of fresh water input from northern Eurasia on stratification of the Arctic Ocean and global thermohaline circulation?

3. How has the land-shelf system responded to variable environmental/ climatic conditions during the Holocene? Does the paleorecord provide an assessment of the direction and magnitude of potential environmental responses with future climate change?

deglacial rise in sea level progressively shifted sea-ice formation to the shelf providing more sediment for entrainment (Pfirman et al., 1989). Elevated summer sea-surface temperatures inferred for Nordic Seas during the early Holocene, ca. 9000 to 6000 yr B.P. (Salvigsen et al., 1992; Jones, 1994b) imply significantly reduced sea-ice cover, probably less than the historic minima. Conversely, the southern limit of permanent sea ice may have extended onto the Russian shelf seas during the Little Ice Age or other neoglacial events.

BIOGEOCHEMICAL CYCLING AND ECOSYSTEM DYNAMICS

Understanding ecosystems in northern Eurasia is critical for assessing terrestrial and marine sources, sinks, and transformations of carbon, nitrogen and associated greenhouse gases. The shallow shelf seas of the Russian Arctic support a diverse ecosystem mostly nourished by the availability of light and nutrients. Light, in turn is modulated by sea-ice extent and thickness during the warmer months and also by turbidity arising from runoff, melting of sediment laden sea ice, and by resuspension events. The inflow of Pacific waters through the Bering Strait is a major source of nutrients for some shelf seas, with rivers probably supply significant local inputs. Biogeochemical cycling in shelf sediments is both a significant source and sink for nutrients to and from the overlying waters (Codispoti et al., 1991). Surface productivity often peaks with maximum nutrient availability at the sea ice edge, and in areas of river discharge. Areas of high primary productivity support benthic amphipod and bivalve communities, that nourish marine mammals and fish stocks which in turn are important resources for native/local hunters.

The watershed and shelves of northern Eurasia support a rich avian, marine and terrestrial fauna and flora. The viability of this ecosystem is inherently linked to the nutrients and the contaminants delivered by river and shelf waters. Elevated radionuclide, metal, and organochlorine levels have recently been associated with run-off from many Russian rivers. There is uncertainty of the effect of these contaminants on Arctic biodiversity and the sustainability of human populations in Siberia.

Riverine Flux and Coastal Erosion: A Source for Productivity Limiting Nutrients

Summer run-off from landscapes dominated by organic-rich soils and mires of northern Russia is an important source of nutrients for shelf seas. Rivers of northern Eurasian with large catchment areas, such as the Ob, Lena, and Yenisei Rivers serve to focus runoff and nutrients in estuaries and deltaic environments. River discharge is highly seasonal with up to 90% of the yearly volume delivered during June and July, often beneath sea ice cover. Changes in the melt season and precipitation patterns in northern Eurasia could substantially alter the amount and seasonal delivery of fresh water and associated nutrients into Arctic seas.

The productivity of the Arctic Ocean and adjacent shelf seas is projected to increase with global warming. Future scenarios portray reduced sea ice cover increasing light availability and greater nutrient flux with enhanced wind mixing over shelf seas (Walsh, 1989). However, this assessment does not fully consider the effect of greater precipitation or changes in river discharge on shelf processes and nutrient availability. Enhanced river discharge could increase stratification within the Arctic Ocean basin, limiting the cycling of nutrients.

Specific Recommendations
1. Evaluate biogeochemical fluxes and biodiversity for the Bering Strait area.

2. Examine fluxes from the watershed, through deltaic and shelf environments and effects on biodiversity and productivity

3. Development of landscape scale models to enhance extrapolation of surface processes to larger scales

Another potential source of productivity limiting nutrients is from coastal erosion and permafrost degradation. Coastal retreat of 1 to 10 m/year, usually concentrated during open water season, delivers particulate and dissolved organic matter to the near-shore zone during a period of maximum productivity. The collapse of coastal cliffs containing ground ice is a pervasive phenomenon in the Russian Arctic providing a less focussed nutrient source than fluvial input.

The sequestering and dissemination of nutrients from continental shelves into the Arctic Ocean basin is linked to halocline formation and biologic activity. The highest productivity on the continental shelf is often where river and marine waters mix, supporting phytoplankton blooms. However, some of the dissolved nutrients delivered by rivers descend into the halocline and are advected into the Arctic Ocean. These shelf-borne nutrients within the upper halocline can enhance Arctic Ocean productivity, if mixed into the surface water by wind-driven mixing, ice keel stirring, and shelf-edge breaking of internal waves.

BIOGEOCHEMICAL CYCLING AND ECOSYSTEM DYNAMICS RESEARCH PRIORITIES

The source and fate of productivity limiting nutrients from Eurasian watersheds to Russian shelf seas and pan-arctic transport is poorly known. The three Russian rivers with the largest discharge, the Ob, Yenisei and Lena Rivers are important for focussing nutrients and contaminants from broad areas of northern Eurasia into the Arctic. However, other drainages (Katanga River) with a magnitude less discharge, such as the Pur River that empties into the Kara Sea, delivers more total organic carbon than the Yenisei River. Thus, small drainages may equally influence shelf processes. Questions remain as to the interannual variability of river discharge, nutrient availability and sequestering in estuaries, sea-ice extent, and shelf productivity. There is a clear need to obtain a greater understanding of shelf productivity and biodiversity with ameliorated climate conditions, perhaps similar to conditions during the early Holocene. This discussion group distilled two major research questions.

1. What are the effects of altered climate to biodiversity, landscape evolution, and ecosystem dynamics on land and water?

2. What are the effects of altered run-off to the biological productivity and nutrient cycling on the Arctic Shelf?

CRYOSPHERE INTERACTIONS

Paleoclimatic records from the Greenland ice sheet and the deep North Atlantic Ocean divulge rapid fluctuations in the ocean and the atmosphere system within timescales of human generations, underscoring the sensitivity of the climate system beyond historic variability. There is a clear need to define climate boundary conditions on longer timescales of the Holocene (10,000 yr B.P.), the last deglaciation (20,000 yr B.P.), and the last interglaciation (150,000 yr B.P.) to understand better the response of the climate system to rapidly changing forcings, similar in context to present greenhouse warming.

The sensitivity of the Earth System to climate change can not be completely assessed without a better knowledge of the past extent of Arctic sea-ice and land ice. Changes in sea ice and glacier coverage in the Arctic may result in fundamental shifts in the climate system by increasing global albedo and altering the planetary wave pattern (Kutzbach and Guetter, 1986; Ruddiman and Kutzbach, 1989). Sea ice, meltwater and iceberg discharge from the Arctic can lead to dramatic changes in the ventilation rate of the deep ocean, altering the global ocean heat budget, CO_2-uptake and nutrient balance (Charles and Fairbanks 1992; Veum et al., 1992). Our understanding of the climatic links between the cryosphere, atmosphere, and oceans are hampered because of an incomplete knowledge of the distribution of past ice sheets, sea ice and permafrost in the Russian Arctic.

The distribution of glaciers, and sea ice have had significant impact on human adaptations in Arctic regions. The growth of ice sheets have blocked and facilitated the movement of humans and biota across the Arctic and lower latitudes. The extent and seasonality of sea-ice coverage has controlled the movement of marine mammals, and the development of indigenous fisheries, critical resources for human survival.

One of the largest uncertainties in ice volume changes during the late Quaternary are the areal and vertical extent of ice sheets over the extensive shallow shelves bordering northern Eurasia. Glacial-maximum ice sheet reconstructions range from nearly complete glacier coverage of northern Eurasia area by a contiguous marine-based ice sheet (e.g. Grosswald, 1993; Peltier, 1994) to individual ice sheets/caps centered on the Arctic archipelagos and advancing onto the adjacent shelf (e.g. Siegert and Dowdeswell, 1995). The discrepancy between reconstructions is equivalent to the volume of two Greenland ice sheets. An important implication of this discrepancy is that ice sheet extent and height parameters for the latest generation of general circulation models may be in error and offer an unrealistic paleoclimate assessment.

Specific Recommendations

1. Gather field evidence to test the existence or lack thereof of Late Valdai ice sheet over the Laptev, and East Siberian Seas and adjacent terrestrial areas.

2. Determine limits of glacial-isostatic compensation and glaciation for lowlands and islands fringing the Kara Sea.

3. Study marine and raised marine strata in the Kara and Laptev Seas to evaluate late glacial and last interglacial environments and ice sheet extent.

4. Retrieve long sedimentary records from shelf basins, troughs, or deep lakes that record environmental events since the last interglaciation.

Equally unresolved are the climatic conditions conducive for inception and disintegration of ice sheets and glaciers in the Russian Arctic. An important observation is the apparent difference in magnitude of Late Weichselian and older glaciations across the Russian Arctic. Large marine-based ice sheets may have been confined to the Barents and Kara Seas. In contrast, glaciation of the eastern Russian Arctic was more restrictive, characterized by ice cap and valley glacier expansion, with vast shelf areas of the Laptev, East Siberian, and Chukchi Seas exposed (Fig. 5).

Knowledge of the timing and volume changes of ice sheets over the continental shelves of Russia between 15,000 and 10,000 yr B.P. are insufficient to understand the links between the episodic rise in global sea level, potentially related to iceberg discharge events of Laurentide and Fennoscandinavian ice sheets to demise of northern Eurasian glaciers (Broecker et al., 1992). Marine margins of shelf-based ice sheets, at least in the Barents Sea, are particularly susceptible to sea level rise, with outlets terminating in the >500 m deep troughs feeding into the Arctic Ocean. The balance between glacial isostasy and global eustasy during the Holocene is poorly known for many continental shelves in the Russian Arctic. A notable exception is the Barents Sea shelf where there is clear evidence for a Late Weichselian grounded ice sheet and Holocene sea level changes dominated by glacial isostasy (Forman et al., 1995).

Drilling in the eastern Siberian lowlands reveal permafrost extending to >500 m depth. In some areas, terrestrial permafrost is interbedded with sediments and exhibits large scale deformational structures that may be relict glacier ice (Astakhov and Isayeva, 1988). Permafrost is pervasive offshore, particularly in the Laptev, East Siberian, and Chukchi Seas. Subsea permafrost in the eastern Arctic often attains thicknesses similar to terrestrial permafrost on the adjacent lowlands. Submarine permafrost is inferred to have formed when shelf seas were exposed during the last global low sea-level stand, ca. >20,000 to 10,000 yr. B.P. Thinner and discontinuous massive-ice occurs under glaciated shelves of the Barents and Kara Seas. Gas hydrates commonly occur beneath and within permafrost and may be a source of atmospheric methane, if not assimilated by methanogenic bacteria.

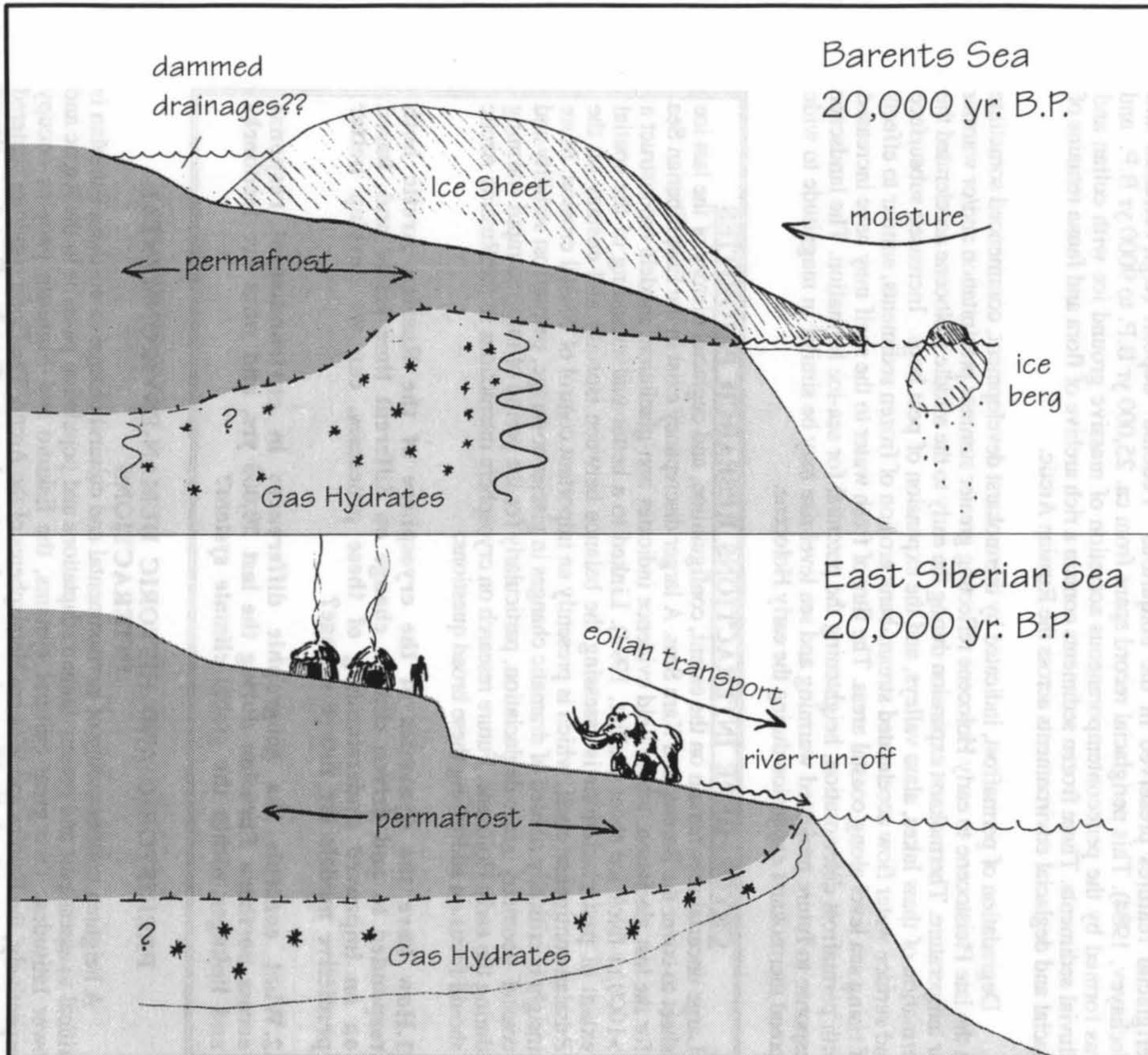

Figure 5: Schematic representation of different events and processes that occurred in the Barents and East Siberian Sea during the last glacial maximum, ca. 20,000 years ago.

Climate conditions during the last glaciation for lowlands east of the Ural Mountains to the Bering Strait were colder and possibly dryer than today as inferred from the many periglacial features preserved in the ubiquitous "Yedoma" deposit (e.g.,Velichko and Nechayev, 1984). This periglacial record spans from ca. 25,000 yr B.P. to 9000 yr B.P. and was formed by the penecontemporaneous accretion of massive ground ice with eolian and alluvial sediments. These frozen sediments contain a rich archive of flora and fauna remains of glacial and deglacial environments across the Russian Arctic.

Degradation of permafrost, indicated by thermokarst development, commenced sometime in the late Pleistocene to early Holocene reflecting greater summer precipitation and/or warmer air temperature. Thermokarst expansion during the early to the middle Holocene accelerated the formation of thaw lakes, alass valleys, and the expansion of peat bogs. Increased subsurface and surface water flow accelerated stream-bank erosion of frozen sediments, similar to effects of rising sea level along coastal areas. The flux of fresh water to the shelf may have increased with permafrost deterioration, heightening the potential for sea-ice formation. The landscape response to future projected warming and sea level rise may be similar in magnitude to wide spread thermokarst expansion during the early Holocene.

CRYOSPHERE INTERACTIONS RESEARCH PRIORITIES

Large uncertainties remain on the extent, configuration, and deglacial history of the last ice sheet to cover the Barents and Kara Seas. A larger discrepancy exist in the East Siberian Sea for the last glaciation, where field evidence indicates non-glaciation, models reconstruct a >1000 m thick ice sheet (Peltier, 1994). Linked to a better understanding of the spatial extent of past glaciations is assessing the balance between isostasy and eustasy on the Russian continental shelf, which is presently an important control of coastal erosion. More insight is critically needed of dramatic changes in glacier coverage, permafrost stability and coastal geometry since deglaciation, particularly for the period of inferred rapid warming during the early Holocene. Future research on cryosphere interactions in the Russian Arctic should focus on addressing these broad questions:

1.How have the dynamics of the cryosphere of the Russian Arctic both responded to and driven climate change on different time scales and, based on an improved understanding of these processes, can we develop better predictive models for future change?

2.What controls the geographic differences in environmental response across northern Eurasian during the last 20,000 yrs, and what are feedbacks and linkages within the global climate system?

PREHISTORIC AND HISTORIC HUMAN-ENVIRONMENTAL INTERACTIONS

A heighten understanding of environmental and cultural change in northern Eurasian is critical to assess past and present human adaptations and population patterns in the Arctic and lower latitudes. Two great cultural systems, the Eskimo and Euraisan peoples occupy respectively, the Eastern and Western Hemispheres of the Arctic. The Eskimo culture centered in the Beringian-North Pacific region, spread eastward across Canada. Eurasian cultural tradition probably spawned Arctic populations of Scandinavia and northern Russia. However, little is known about the roots of the Eurasian Arctic cultures, particularly in comparison to cultural development in the Americas. Many critical cultural changes (e.g. Mesolithic technology, ceramics, and shamanistic practices) appear to have occurred first in the Eurasian north and spread later to North America. Outstanding questions on the timing and pathways of human migrations to the Americas, concomitant environmental/climatic controls and technological transfer can not address without a deeper understanding of Eurasian Arctic cultural tradition.

There is a rich history of human habitation in northern Eurasia spanning much of the late Quaternary. The watersheds and continental shelf seas of the Russian Arctic provided a variety of natural resources for sustenance of past and future human populations. Environmental and climate changes, particularly in the past 20,000 years have had significant impacts on human, animal, and plant populations inhabiting the Russian Arctic. This region was mostly ice-free during the late Quaternary, served as a refugia for ice-age biota in the Holocene, and a staging area for human dispersal into the Americas.

New cultural adaptations emerged during the latest period of rapid environmental and climate change, the transition from the Pleistocene to the Holocene, ca. 14,000 yr B.P. to 8,000 yr. B.P. Resource utilization shifted from a dominance of terrestrial-mammal hunting to a greater exploitation of marine and riverine stocks. A reduction in sea ice extent during the early Holocene allowed humans to occupy high Arctic islands, such as Zhokhov Island at 77° N within the present limit of permanent pack-ice (Makeyev et al., 1993). Extended open water conditions facilitated the development of sea mammal hunting adaptations, enhancing the mobility of paleopopulations. The early Holocene expansion of whitefish and salmon stocks into Arctic seas with increased river run-off and extended open water conditions provided new food sources for paleopopulations. Inferred climate cooling in the late Holocene, after 5000 yr. B.P., may have reduced marine and riverine food stocks potentially leading to the out migration of paleopopulations from the Arctic. Cultural adaptations in the last few millennium, such as whaling and reindeer pastoralism, provide new opportunities for the sustenance of Arctic populations.

Specific Recommendations

***1.** Surveys to identify the distribution, history and paleoecological relations of early human occupations , particularly along the shores of the Laptev and East Siberian Seas and high Arctic islands.*

***2.** Expand radiocarbon dating and paleoecological sampling of key archeological sites (e.g., Diuktai, Zhokov and Dirring Sites).*

***3.** Indentificatin of and study of key Russian historical data and archival sources on environmental /human change.*

***4** Comparative regional studies (Lena River vs Indigirka River) of "key zones" as staging points for Asian entry into the New World.*

***5.** Gathering and preservation of traditional ecological knowledge and indigenous groups.*

<u>The Russian Arctic: A Gateway for Human Expansion</u>

The Bering Strait is recognized as a key migratory pathway of human populations and other biota, particularly during global low sea-level stands (Hopkins, 1967). Greater knowledge of paleoenvironments and paleopopulations in the Russian Arctic is essential for deciphering the climatic and/or cultural causations, routes and timing of human migration across Beringia.

Inquiry should focus on records of human occupation from areas east of the Ural Mountains because of the presence of a large indigenous native population, an extensive historical record of native people, and a dearth of archaeological perspective on human occupation. Other cultural adaptations of interest are occupation sites in proximity to

Quaternary ice sheets and glaciers on the Taimyr Peninsula, the low lands surrounding the Kara Sea and the Pechora River basin. A better understanding of the record of human habitation in the high Arctic, such as on Wrangel and Zhokov Islands and Severnaya Zemlya, provide important insight into changes in resource utilization and human adaptation with warmer and cooler climates in the Holocene.

The study of cultural adaptations over the past 20,000 years hold the greatest potential to advance our knowledge of human-environmental interactions in the Russian north. There are abundant archaeological sites that span from the late Pleistocene into the Holocene for which more valuable cultural information could be secured with modest reexcavations and additional radiocarbon control. Unlike Beringia there is abundant evidence in the Russian Arctic for occupation sites >20,000 years old. These sites offer an important perspective on the adaptation of people and biota to full glacial climate and earlier "warm" periods. The Diring Site adjacent to the Lena River at 62°N, is of particular importance because this site provides insights on paleolithic human migration and adaptation in a subarctic environment.

Continuity and Preservation of Traditional Environmental Knowledge

The local populations of northern Russia possess valuable knowledge of a variety of Arctic phenomenon, such as weather extremes, sea-ice and permafrost conditions, coastal and river erosion rates, plant distributions, and game, fish and sea-mammal migration cycles. The intimate understanding of the environment held by indigenous people in North America has been acknowledged through various documentation programs. Similar recognition and new science partnerships are needed for Russian indigenous populations. There is concern that invaluable traditional perspective on Arctic environments and lifeways will be lost through general cultural assimilation, passing of knowledgeable elders, and abandonment of native languages and subsistence activities by younger generations. Special efforts are needed to document native environmental and cultural wisdom, to facilitate the integration of this information into scientific assessments. Western scientists are encouraged to assist in the preservation and documentation of indigenous wisdom by assisting with local publication and education.

Information on traditional subsistence provides important perspectives on past and future cultural changes in the Arctic. Case in point, is the continuity of reindeer pastoralism for at least the past millennium in northern Eurasia and the possible resurgence of this lifeway in Russia with recent political changes (Krupnik, 1993). Beyond the need for ethnographic information, there is intrinsic value in facilitating the preservation and continuity of native lifeways in the Russian Arctic. Many indigenous populations have survived centralized government control of the former Soviet Union, but their traditional lifeways are currently threatened by economic pressures and pollution. Hence, data on traditional responses to past environmental and cultural change may be crucial to preserving and reinvigorating traditional cultures in northern Eurasia.

PREHISTORIC AND HISTORIC HUMAN-ENVIRONMENTAL INTERACTIONS CRITICAL RESEARCH QUESTIONS

No place on earth is so little known about the history of human adaptations than in northern Eurasia. This region was largely ice free during the late Quaternary, served as a refugia for ice-age biota in the Holocene, and a staging area for the dispersal of humans into the Americas. Northern Eurasia and Beringia are key areas for resource procurement for past and present societies and offers an unique perspective on long-term human responses to climate change. In comparison to Beringia, the Russian Arctic contains a long history of human occupation, spanning at least the past 40,000 years. Today, there are a number of indigenous societies practicing traditional lifeways, providing continuity with past cultures. The most salient research questions are:

1. What environmental changes and/or cultural adaptations facilitated the migration of humans across northern Eurasia to the Americas?

2. How have indigenous populations adapted to changes in resource availability and environmental change?

3. How has the human factor affected the natural evolution of the Arctic and the global system? and What are the potential cultural strategies for future climate change?

CROSS-CUTTING RESEARCH FOCUS

Global questions on climate change necessitates cross-disciplinary inquiry on how the Earth operates as an integrated system in the past, present, and future. The diversity of scientific interests and insights presented at this workshop facilitated assessment of the critical knowledge needed to understand better the response and sensitivity of the Arctic environment and biota to climate change. Discourse emphasized the driving physical processes, the potential controls on biotic responses and the ultimate effect on the human condition. Specifically, the importance of freshwater input and sea level change resonated throughout the discussions as critical factors governing environmental response in the Russian Arctic and modulating climate conditions (Fig. 6).

Abiotic Impact	Biotic Impact	Global/Societal Impact
Sea level change coastal erosion/ Permafrost degradation	Nutrient flux via watershed-deltaic system	Trans-Arctic trace gas and contaminant flux; effect on marine productivity
Changes in shelf configuration & hydrology on Arctic Ocean stratification	Shelf productivity; Changes in present and past flora and fauna populations	Global thermohaline and radiative balance

Figure 6: Critical factors governing land-shelf interactions in the Russian arctic and potential biotic and societal impacts.

Discussions underscored the preeminence of fresh water discharge from Russian rivers on processes controling the stratification of the Arctic Ocean. Understanding the interaction of

Arctic water masses with warmer waters from the Pacific and Atlantic Oceans is pivotal for assessing changes in global heat and precipitation distribution and ventilation of the ocean. Vexing questions remain on the response of Arctic watersheds particularly during periods of rapid climate change, similar in context to the late-glacial and episodes in the Holocene.

Deltaic and estuarine systems are recognized to integrate continental scale biogeochemical processes that deliver nutrients to the continental shelf and eventually to surface waters in the Arctic Ocean. The continental shelves of Russia support a rich ecosystem, sustained by riverine nutrients, that provided resources for expansion of human populations across the Arctic. Today, these same rivers deliver environmental contaminants that effect the Arctic ecosystem and challenge the effective use of Arctic resources.

Of equal concern is the course of sea level and concomitant effect on the rate of coastal erosion and permafrost degradation. The coastline configuration and shelf extent has changed dramatically with Holocene inundation of Russian epicontinental seas and concomitant coastal retreat. Coastline changes will probably continue unabated in the future with the rise in global sea level of 1 to 2 mm/year. A potentially ubiquitous source of productivity limiting nutrients and contaminants to the shelf is dissolved and particulate matter released with coastal erosion and permafrost degradation. In turn, large scale thermokarst and coastal retreat presents a challenge for past, present, and future habitations on the Arctic coastline.

Many participants stressed the inadequate state of knowledge for many environmental parameters in the Russian Arctic, reflecting the remoteness of the region and restricted access during the past fifty years. However, many struggling institutions in the former Soviet Union house data archives containing century-long time series of climate, river hydrology, sea-surface temperatures, and other environmental phenomenon. A unanimous assessment was the need to preserve and integrate existing information and wisdom from indigenous people to develop stronger, and mutually beneficial scientific partnerships with Russian colleagues.

REFERENCES CITED

Aagaard, K., and Carmack, E.C., 1989, The role of sea ice and other fresh water in the Arctic circulation: Journal of Geophysical Research v. 94, p. 14,485-14,498.

Aagaard, K., J. H. Swift, J.H., and Carmack, E.C., 1985, Thermohaline circulation in the Arctic mediterranean seas: Journal of Geophysical Research v. 90, p. 4833-4846.

Aagaard, K., Foldvik, A., and Hilman, S.R., 1987, The West Spitzbergen Current: Disposition and water mass transformation: Journal of Geophysical Research v. 92, p. 3778-3784.

Astakhov, V. I. and L. L. Isayeva, 1988, The "Ice Hill": An example of 'Retarded deglaciation in Siberia: Quaternary Science Reviews v. 7, p. 29-40.

Barnett, T.P., 1990, Recent Changes in Sea Level: A Summary *in* Sea-Level Change: Washington, D.C., National Academy Press, p. 171-183.

Broecker, W., Bond, G., Klas, M., Clark, E. and McManus, J., 1992, Origin of the northern Atlantics Heinrich events: Climate Dynamics v. 6, p. 265-273.

Bryan, F., 1986, High latitude salinity effects and interhemispheric thermohaline circulation Nature v. 323, p. 301-304.

Carmack, E. C., 1990, Large Scale Physical Oceanography of Polar Seas, in Polar Oceanography, A, ed. W.O.Smith, Academic Press, New York, 171-222.

Codispoti, L.A., Friederich, G.E., Sakamoto, C.M. and Gordon, L. I., 1991, Nutrient cycling and primary production in the marine system of the Arctic and Antarctic: Journal o f Marine Systems v. 2, p. 359-384.

Charles, C. D. and R. G. Fairbanks, 1992, Evidence from southern Ocean sediments for the effect of North Atlantic deep water flux on climate: Nature v. 355, p. 416-419.

Fairbanks, R. G., 1989, A 17,000 year glacio-eustatic sea-level record: influence of glacial melting on the Younger Dryas event and deep-ocean circulation: Nature v. 342, p. 637-642.

Forman, S. L., Lubinski, D., Miller, G. H., Snyder, J., Matishov, G., Korsun, S. and Myslivets, V., 1995, Post-glacial emergence and distribution of late Weichselian ice sheet loads in the northern Barents and Kara Seas, Russia: Geology v. 23, p. 113-116.

Gornitz, V. and Lebedeff, S., 1987, Global sea-level changes in durin the past century *in* Nummedal, D., Pilkey, O. H., and Howard, D.F. eds. Sea-Level Fluctuation and Coastal Evolution: Tulsa, Oklahoma, Society of Economic Paleontologists and Mineralogists Special Publication 41, p. 3 -16.

Gordeev, V.V., Martin, J.M., Sidorov, I.V. and Sidorova, M.V., in press, A reassessment of the Eurasian River input of water, sediment, major elements and nutrients to the Arctic Ocean. American Journal of Sciences.

Grosswald, M. G., 1993, Extent and melting history of the Late Weichselian ice sheet, the Barents-Kara continental margin; in Peltier, W. R., ed. Ice in the Climate System, Springer-Verlag, New York, p. 1-20.

Hopkins, D. M., 1967, The Bering Land Bridge, Standford University Press, California.

Jones, G. A., 1994a, An abiotic central Arctic Ocean during the last glcial maximum: Evidence for an Arctic ice shelf?: EOS Transactions v. 75, p. 226.

Jones, G. A., 1994b, Holocene climate and deep ocean circulation changes: Evidence from accelerator mass spectrometer radiocarbon dated Argentina Basin (SW Atlantic) mudwaves: Paleooceanography v. 9, p. 1001-1016.

Kutzbach, J. E. and Guetter, P. J., 1986, The influence of changing orbital parameters and surface boundary conditions on climate simulations for the past 18000 years: Journal of Atmospheric Sciences v. 43, p. 1726-1759.

Krupnik, I., 1993, Arctic Adaptions, Native Whalers and Renideer Herders of Northern Eurasia, Dartmouth College/University of New England Press, Hanover, New Hampshire, 355pp.

Lambeck, K., Johnston, P., and Nakada, M. 1990, Holocene glacial rebound and sea-level change in NW Europe: Geophysical Journal International v. 103, p. 451-468.

Loeng, H., 1991, Features of the physical oceanographic conditions of the Barents Sea: Polar Research v. 10, p. 5-18.

Makeyev, V. M., Pitul'ko, V. V. and Kasparov, A. K., 1993, The Natural environment of the De Long Archipelago and ancient man in the late Pleistocene and early Holocene: Polar Geography and Geology v. 17, p. 55-63.

Midttun, L.,1985, Formation of dense bottom water in the Barents Sea. Deep-Sea Research v. 2, p. 1233-1241.

Mochanov, Y. A., 1993, The most ancient Paleolithic of the Diring and the problem of a nontropical origin for Humanity: Arctic Anthropology v. 30, p. 22-53.

Nürnberg, D., Wollenburg, I., Dethleff, D., Eicken, H., Kassens, H. Letzig, T., Reimnitz, E., and Theide, J., 1994, Sediments in Arctic sea ice: implications for entrainment, transport and release: Marine Geology v. 119, p. 185-214.

Oechel, W.C. and Vourlitis, G.L., 1994, The effects of climate change on land-atomosphere feedback in Arctic tundra regions. TREE v. 9 (9), p. 324-329.

Oechel, W.C., Hastings, S. J., Vourlitis, G., Jenkins, M., Riechers, G., Grulke, N., 1993, Recent change of Arctic tundra ecosystems from a net carbon dioxide sink to a source.

Nature v. 361, p. 520-523.
Peltier, W. R. 1994, Ice Age Paleotopography. Science v. 265, p. 195-201.
Peltier, W. R. and Tushingham, A.M, 1989, Global sea level rise and the greenhouse effect: might they be connected?: Nature v. 244, p. 806-810.
Pfirman, S.L., Wollenburg, I., Thiede, J. and Lange, M.A., 1989, Lithogenic sediment on Arctic pack ice: potential aeolian flux and contribution to deep sea sediments. *in*: Leinen, M. and Sarnthein, M. eds. Paleoclimatology and Paleometeorology: Modern and Past Patterns of Global Atmospheric Transport, NATO ASI Series C, Kluwer Academic Publishers, The Netherlands, 282: 463-493.
Reason, C. J. C. and Power, S. B. 1994, The influence of the Bering Strait on the circulation in a coarse resolution global model. Climate Dynamics v. 9, p. 363-369.
Reimnitz, E., Dethleff, D. and Nürnberg, D., 1994, Contrasts in Arctic shelf sea-ice regimes and some implications: Beaufort Sea versus Laptev Sea. Marine Geology v. 119, p. 215-225.
Ruddiman, W. F. and J. E. Kutzbach, 1989, Forcing of late Cenozoic Northern Hemisphere climate by plateau uplift in southern Asia and the American west: Journal of Geophysical Research v. D15, p. 18,409-18,427.
Salvigsen, O., Forman, S. L. and Miller, G. H., 1992, The occurrence of extralimital thermophilous molluscs on Svalbard during the Holocene and paleoclimatic implications: Polar Research v. 11, p. 1-10.
Siegert, M. J. and Dowdeswell, J. A., 1995, Numerical modeling of the Late Weichselian Svalbard-Barents Sea ice sheet: Quaternary Research v. 43, p. 1-13.
Stein, R., Nam, S.-I., Schubert, C., Vogt, C., Fütterer, D. and Heinemeier, J., 1994, The last deglaciation event in the eastern central Arctic Ocean: Science v. 264, p. 692-696.
Vartanyan, S. L., Garutt, V. E. and Sher, A., 1993, Holocene dwarf mammoths from Wrangel Island in the Siberian Arctic: Nature, v. 362, p. 337-340.
Velichko, A.A. and Nechayev, V.P., 1984, Late Pleistocene Permafrost in European USSR. in ed., Late Quaternary environments of the Soviet Union. University of Minnesota Press, Minneapolis, p. 79-86.
Veum, T., Jansen, E., Arnold, M., Beyer, I., and Duplessy, J-C. 1992, Water mass exchange between the North Atlantic and the Norwegian Sea during the past 28,000 years: Nature v. 356, p. 783-785.
Walsh, J.J., 1989, Arctic carbon sinks: present and future. Global Biogeochemical Cycles: v. 3, p. 393-411.
Watson, R.T., Rodhe, H., Oeschger, H. and Siegenthaler, U., 1990, Greenhouse Gases and Aerosols, in Houghton, J. T., Jenkins, G. J. and Ephraums, J. J., Ed. 1990: Climate Change, IPCC Scientific Assessment. Cambrigde University Press, New York, p. 5-40.

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Report of "EURASIAN ARCTIC LAND-SHELF SYSTEM: Follow-Up Arlington Workshop"

held at Texas A & M University offices
Arlington, Virginia
October 16th-17th, 1995

Workshop Report Editors: G. Leonard Johnson and Steven L. Forman

FOREWORD

A follow-up meeting to the Columbus Workshop was held October 16th -17th, 1995 at the offices of Texas A & M University in Arlington, Virginia. Twenty people attended, many who participated in the Columbus workshop (Table 1). This meeting gave additional focus on scientific objectives for a potential ARCSS-NSF program and provided preparatory input for a Russian-lead workshop in St. Petersburg, Russia in November, 1995. Participants provided guidance on integrating with the various Russian science structures. Discussions also ensued on establishing safe, joint field-logistics with Russian colleagues, with requests to NSF for better logistical support. Participants addressed similar science components to those discussed at the Columbus meeting and are presented below.

Table 1: Participants of the Arlington Meeting

Julie Brigham-Grette, Univ. of Massachusetts-Amherst
Jerry Brown, International Permafrost Association
Louis Codispoti, Old Dominion University
Lee Cooper, Oak Ridge National Laboratory/University of Tennessee
Steve Forman, Ohio State University
William Fitzhugh, Smithsonian Institution
Leonard Johnson, Texas A & M University
Igor Krupnick, Smithsonian Institution
Michael Ledbetter, National Science Foundation, Office of Polar Programs
Glenn MacDonald, University of California, Los Angeles
Gifford H. Miller, University of Colorado
Walter Oechel, San Diego State University
Stephanie Pfirman, Barnard College/Columbia University
Tom Pyle, National Science Foundation, Office of Polar Programs
Nikolai Romanovskii, Moscow State University
Renee Tatusko, NOAA, Working Group VIII
Patrick Webber, Michigan State University

FLUX OF WATER, ICE, CONTAMINANTS, AND NUTRIENTS

The continental shelf of northern Eurasia is a source area for fresh and saline water, sea ice, and sediments into the Arctic. The variability of fresh water and sea-ice flux into high latitude oceans is critical for mitigating thermohaline circulation and influencing poleward flux of Atlantic and Pacific waters. Paleoceanographic studies have documented rapid reorganizations of thermohaline circulation over the past 20,000 years. However, the role of Eurasian sea-ice and riverine flux on changes in thermohaline circulation is poorly known.

Participants underscored that variations in Siberian river discharge and sea-level change of shallow shelf seas are important environmental parameters that control fluxes to northern seas. Inquiry should focus on the continuum of environmental responses covering the past 20,000 years to the present. Landscape-hydrologic models need to be developed to assess the potential responses to natural and anthropogenic changes into the next century.

Research Priorities

1. What changes occurred in river discharge during glaciations, with potential ice sheet diversion of rivers and changes in atmospheric circulation? When did discharge of the Ob

and Yenisei rivers re-initiate with deglaciation?

2. What are influences of Siberian river run-off on thermohaline circulation and "estuarine" return flow of intermediate and deep Atlantic water?
3. How has sediment and nutrient delivery to shelf seas and the Arctic Ocean varied with rising sea level in the Holocene?
4. What are the seasonal and interannual variations in river discharge, and sediment and contaminant flux from Eurasian watersheds to shelf seas.
5. Where are depositional centers for river-derived sediments and what processes may lead to remobilization of potentially contaminant-bearing sediments?

Research Questions on Sea Level Change

1. What is the timing and geometry of paleo-shorelines with Holocene sea level rise?
2. What is the rate of coastal erosion and flux of sediments with Holocene sea level rise?
3. What is the response of the sea-ice/shelf system during warmer periods in the Holocene?
4. When and how did sea level rise lead to the current processes:
   A. sediment entrainment by sea ice and advection off-shelf
   B. formation of shelf brines and advection off-shelf
   C. establishment of the Siberian Coastal Current
   D. the development of a shelf-break polynya system

Implementation Strategies

1. Obtain hydrographic time series data for Eurasian rivers.
2. Maintain and expand Russian river monitoring sites.
3. Develop new instrumentation to establish year round environmental monitoring of specific sites on the shelves.
4. Arrange multinational cruises/expeditions to obtain long, well-dated, high resolution cores from selected depocenters for understanding variations in fluxes due to natural and anthropogenic changes (e.g. contaminant input, changes in sediment flux due to onshore mining and damming activities).
5. Develop watershed to shelf mass-balance models to evaluate potential changes in the hydrologic cycle with climate change and anthropogenic inputs.

BIOGEOCHEMICAL CYCLING

Major fresh-water sources for the Eurasian north are Siberian river discharge and Pacific water inflow through the Bering Strait. The volume of fresh water from the Pacific Ocean is similar in volume to the freshwater contributions from rivers (2960 km^3). A major link between the land and shelf components in the Eurasian arctic are fluxes of dissolved organics and particulates with riverine input. Additional and unquanitified amounts of dissolved and particulate organic material are contributed through widespread shoreline erosion.

Possible future changes in the runoff of Arctic rivers, the volume of nutrient-rich water flow through Bering Strait, and sea-level rise will have an effect on the fluxes of water-borne materials to the continental shelves. The environmental responses to varying nutrient inputs are not immediately predictable and indicate the need for new processes oriented studies of biogeochemical exchange between continental shelves and northern Eurasia. These studies should include analyses of current processes of land-to-sea exchange, and modeling responses with changes in precipitation, sea ice coverage, temperature, and food-web structure.

In planning these activities, particular care should be directed towards minimizing logistical costs by selecting sites that are scale appropriate for deciphering regional environmental effects. Ice-breaker support is preferred for shelf and slope based inquiry. However, some logistical uncertainties remain in executing river and estuary studies, particularly during break-up of river ice when there maybe high fluxes of water, sediments, and organic material.

Research Priorities:

1. How will changes in river flow and freshwater contributions through Bering Strait effect thermohaline circulation on a large scale, and regional circulation such as of the Siberian Coastal Current?
2. What percent of dissolved and organic materials in river runoff remain in estuaries? How much is deposited in shelf sediments, and what part is incorporated into marine food webs?
3. Does organic matter eroded from coastal sediments have a different biogeochemical fate from organic material brought to northern seas through river runoff?
4. Do paleoclimate records provide indications of different biogeochemical processes and hydrology under alternate ecological conditions, e.g. with a more northern treeline?
5. What biogeochemical and sedimentary distribution processes will be significantly affected by changes in sea ice production?
6. If the average extent of sea ice coverage in the Arctic Ocean retreats, will there be an increase in primary production in ice-free shelf waters?

CRYOSPHERE GROUP

Existing knowledge of the Russian arctic indicates that large marine-based ice sheets repeatedly occupied the western Eurasian arctic during the Pleistocene. In contrast, the eastern Russian arctic, including most of Siberia and the Russian far east was either ice-free or intermittently host to small complexes of valley glaciers. The reason for this strong east to west gradient is not clear, but is likely to be intimately related to moisture sources. For example in Alaska, paleoecological data, and geomorphic evidence indicate that the regions were extremely arid during the last glacial maximum. Inquiry should focus on defining glacier limits across northern Eurasia.

There is a clear need early on for the translation of relevant literature from Russian to English. Equally important is the acquisition and archiving of existing data bases (e.g., air and soil temperatures, snow lines) to complement existing data bases (e.g., NOAA data centers). As this program ramps up, a proposal for translation and archiving would facilitate later proposals and improve the development of sound science objectives. Moreover, it would send a message to our Russian colleagues that we see this project as a real partnership, and not "colonial science".

Research Priorities

1. What are the reasons for the dramatic differences in glacial history on the arctic shelves from east to west? There is a critical need to define the environmental and climatic conditions of the unglaciated regions.
2. What is the role of the Arctic Ocean in thermohaline circulation? What is the role of the arctic shelves in deep water production? Given that we know of rapid reorganizations of thermohaline circulation over the past 40,000 yr, what was the role of riverine and shelf input on those changes?

Data/Information Needs

1. Relative sea level record in glaciated and unglaciated regions and how this was linked with human occupation.
2. Need to determine distribution and thickness of subsea and terrestrial permafrost
3. Need high resolution records of seasonal duration and extent of shelf sea ice
4. Need studies of paleohydrology--history of fresh water input to the russian shelves.

HUMAN-ENVIRONMENTAL INTERACTIONS AND RESPONSES TO PAST AND PRESENT ENVIRONMENTAL CHANGE

Recent archeological discoveries call into question previous views of the age and geographic extent of human settlement in the Russian arctic. Claims of extreme antiquity (ranging from 400,000 yr to 4 myr) for sites in the Lena River basin; a 25,000 yr old mammoth kill in the Pechora River basin; reports of human settlements in extreme northern locations in Franz Josef Land; a virtually intact 8000 yr old frozen Mesolithic village on Zhokov Island at the edge of the continental shelf in the Laptev Sea; and persistence of dwarf mammoths on Wrangel Island until 3700 yr ago on Wrangel Island all draw attention to the need for expanded human-environmental research in this vast, sparsely populated region of the globe.

Cultural and Environmental Diversity

The Russian arctic has a rich archeological and paleoecological archive along rivers and coasts. This cultural richness extends to the present with a resident indigenous population that still retains much of its traditional knowledge and way of life. In Siberia, seven major ethnic populations co-exist in Siberia which has greater cultural diversity than the more unified Eskimo/Inuit sphere of the North American Arctic. These indigenous groups have developed distinct local adaptations to a variety of diverse habitats across the Russian arctic.

Gateway to the Americas and Global Change

Anthropological studies in the Russian arctic are important for understanding cultural developments and human-environmental interactions across the Northern Hemisphere. The Russian arctic is at the gateway to the Americas and a source of human population and associated cultural influences/exchanges that propogated various lifeways during the past 15,000 yr.

Science Plan: collaborative investigations following six main themes:

1. History and adaptations of human settlement;
2. Biotic history and human-environmental interactions;
3. Modern processes and biodiversity;
4. Modeling paleo and modern data sets with a view toward predicting future impacts;
5. Cultural and environmental survival emphasizing heritage, education, conservation, and recovery/restoration; and
6. Native and local community involvement.

Research Priorities

1. What environmental changes or cultural adaptations facilitated migrations of humans into and across northern Eurasia into the Americas?
2. How have humans and their cultures responded to Pleistocene-Holocene environmental and resource change?

3. What human impacts have influenced the natural development of the Russian arctic ecosystem?
4. How have these developments had a wider global impact on Eurasian, North American arctic, and other American people and cultures?
5. What cultural processes and strategies exist at present that, together with past data, may provide models for responding to future climatic, environmental, or other global change?

Culture Change

The research proposed explores the relationship between environmental and cultural change. While not assuming direct linkage or evolutionary direction, five periods are indentified of special interest as transforming events:

Late Pleistocene: Paleolithic Settlement (30,000 - 15,000 BP): Dry, cold steppe-tundra; mammoth hunting and first people to enter the Americas via the Bering Strait/Land Bridge
Pleistocene-Holocene transition: Paleolithic to Mesolithic transition (15,000 - 9,000 BP): Cold/dry to warm; megafauna disappear; thermokarst develops i.e. fishing subsistance develops.
Mid-Holocene stability: Mesolithic-Neolithic transition (9,000 - 4,000 BP): Warm climate, caribou dominance; population expansion; increased residential stability; sea mammal hunting started; High Arctic occupied up to 80° N. throughout circumpolar region
Late Holocene: Specialized Economies (4,000 BP to present) Climate changing and cooling, Bronze and Iron Age trade and contacts; specialized economies (sea mammal hunting; inshore fisheries reindeer herding; cultural and adaptation diversity)
Recent: Intensive Reindeer Herding (begins ca. 500-300 BP): Reindeer herding dominates; fur trapping and modern industries are introduced; industrial expansion and trans-arctic navigation.

Process Studies

In addition to investigating critical cultural transformations and their environmental relations, this research should feature studies of modern cultural, biological, and environmental processes. The following studies are needed:

1. To develop proxy data and models for testing against paleo data;
2. To elucidate and record data on modern subsistence types, cultural adaptations, and traditional ecological knowledge; and
3. To use paleo-data to test models for potential future impacts of humans on environment or of environmental/climate impacts on humans.

Report of "EURASIAN ARCTIC LAND-SHELF SYSTEM: ST. PETERSBURG WORKSHOP"

held at Arctic and Antarctic Research Institute
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INTRODUCTION

The broad continental shelves of the Russian arctic, spanning from the Atlantic to Pacific oceans and fringed by the Arctic Ocean are critical areas for the flux of water and ice that modulate Earth's climate. The sensitivity of the Earth system to climate change can not be completely assessed without a better knowledge of present and past environmental conditions of the epicontinental Russian seas and adjacent terrestrial environments. Russian scientists have been conducting research since the 1800's but little of this was published in the open literature in English because access to and information about Siberia was severely restricted by security/governmental policies.

The recently improved access to the polar seas and lands of the Russian arctic provides unparalleled opportunities to heighten understanding of Arctic environmental processes and events. Thus, a workshop sponsored by Arctic System Science Program of the National Science Foundation entitled " Research Priorities for Russian Arctic Land-Shelf Systems" was convened at the Byrd Polar Research Center, The Ohio State University, Columbus, Ohio on January 12th to 14th, 1995. The workshop was attended by approximately sixty biological, geological and social scientists from institutions in Russia, Latvia, the U.S., Canada, Germany, and Norway. The purpose was to assess both scientific issues and levels of interest by the scientific community. The latter was strong. Subsequently another NSF sponsored workshop was held October 16th to the 17th, 1995 at the offices of Texas A&M in Washington D.C. The workshop goals were to sharpen the scientific objectives of the Columbus workshop prior to the meeting with the Russian scientific community. On November 6th to 8th, 1995 a bilateral workshop hosted by the State Research Centre-Arctic and Antarctic Research Institute, Saint Petersburg, Russia and sponsored by the U.S. National Science Foundation was held to better ascertain the research interests of the Russian scientific community. The meeting was attended by approximately 120 Russian scientists, from a broad range of institutes within the Commonwealth of Independent States of the former Soviet Union (Appendix A), representing a broad spectrum of disciplines including the lithosphere, hydrosphere, atmosphere, and social sciences. The meeting objectives were to consider the Columbus workshop report and obtain input from the Russian scientific community on their research priorities, as a basis to draw up an integrated bilateral cooperative scientific plan. This document represents a consensus of the workshop by the Russian scientific community. The Russian workshop followed that of its predecessors and focused on the four major themes: water, ice and sediment fluxes, biogeochemical cycling, cryospheric interactions, and prehistoric and historic human-environmental interactions.

Overriding programmatic goals are identification and reconstruction of climate and environmental parameters for the recent past. This research will focus on two time frames: historical (past 200 years) and the late Pleistocene to Holocene (past 20,000 years). Studies on historic time-scales will provide insight on the continuum of processes and fluxes between terrestrial, shelf, and ocean environments (The Climate Features, 1985). For the paleo-period the problem is reconstruction of climatic fluctuations of the late Pleistocene-Holocene. This would necessitate the study and temporal correlation of Quaternary deposits on land and the continental shelf and slope to give an estimate of sea level oscillations for the past 20,000 years. Due to discontinuities in and poor knowledge of marine deposits, studies of bottom lake deposits are of special value. It is recognized that PALE (Paleoclimates of Arctic Lakes and Estuaries) has a robust program in this field and therefore it is not considered as part of an

Eurasian arctic initiative, but rather as an affiliate program.

WATER, ICE, AND SEDIMENT FLUXES

The marginal Barents, Kara, Laptev, East Siberian and Chukchi seas of the Russian arctic comprise 25% of the total continental shelf area of the world's oceans and with the exception of the Barents Sea lie principally at depths <50 meters (Atlas, 1985, Baskakov et al,1987). Being both large and shallow these shelves are sensitive to sea-level oscillations (Dvorkin and Mustafin, 1977).

The Russian arctic shelves are an "estuary" for the Arctic Ocean where 70% of terrestrial fresh water is derived from the discharge of the Lena, Ob and Yenisei rivers (2960 km^3; Ivanov 1976a and 1976b, Carmack, 1990; Ivanov, 1994 ; Gordeev et al., 1996). The voluminous fresh water discharge into the Arctic estuary reflects the large catchment area (13054 $\times 10^6$ km^2) for rivers draining into the Kara, Laptev, and East Siberia seas. Much of the Russian arctic and subarctic receives relatively low precipitation of 100 to 300 mm/yr (Ivanov, 1976 a; Gordeev et al.,1996). Thus, any change in regional precipitation across continental Russia or impoundment of drainage can alter the delivery of fresh water to northern Arctic seas. In turn, littoral and deltaic sedimentation and cross-shelf sediment transport are strongly influenced by riverine input as are sea ice and marine productivity. The response of terrestrial areas to climatic warming may be largely determined by the changes in precipitation patterns and amounts. For example, the increasing winter precipitation predicted by most models will affect the onset and extent of discharge from the spring snow melt.

These shelf seas are a hemispheric source for sea ice, deep waters and riverine buoyant waters. During the summer the shelves act as positive estuaries with a net outflow of low density water at the surface. Conversely, during the winter the shelves are "reverse estuaries" with a net outflow at depth of high density saline waters created with sea ice formation (Antonov, 1958; Midttun, 1985; Carmack, 1990). These waters move down-slope entraining Atlantic Intermediate Water resulting in the deep waters of the Arctic Ocean (Nikiforov and Shpaikher , 1980; Aagaard et al., 1985; Carmack, 1990). The extent that this process contributes to deep water characteristics, remains under debate .

Research Priorities--Climate

1) Determination of the present climate conditions and changes within the system in the past for the land-shelf-basin system on the basis of existing data and a continuing program of instrumental observations and data collection;
2) Determination of the fresh water balance within the "system" and estimates of its fresh water and salt exchange within the Arctic Basin;
3) Consequences of climatic change in the Russian arctic are not difficult to hypothesize, but at this point, are difficult to quantify. The performance of general circulation models in the Arctic need improvement through better land-surface parameterization, a wider distribution of data and better coupling of terrestrial and oceanic processes, and coupling of the shelf and basin and;
4) Paleoclimate reconstruction and halocline evolution in the Arctic Ocean.

Research Priorities--Rivers

1) Detection of the global change effects in the Arctic-wide "estuarine" system and;
2) The flux of freshwater from the Russian arctic both seasonal and interannual and its influence on shelf circulation and sea ice distribution, biodiversity, sediments, nutrients and ecosystem dynamics on land and the delta/estuarine and marine system.

Research Priorities--Shelf

1) Dynamics of water, ice and suspended load and interaction with atmosphere;
2) Dynamics and processes of the coastal zone and;
3) Cryogenic fluxes of ice, permafrost, glaciers, icebergs.

Research Priorities--Atmosphere

1) The effect of different climate-forming factors (aerosols, clouds, radiation, albedo, synoptic processes;
2) Estimation of the contribution of natural and anthropogenic sources to the variability of climatic parameters and contamination levels of the Arctic atmosphere, as well as prediction of the distribution of contaminants and;
3) Study the effects of solar activity in the stratosphere and in weather phenomena.

BIOGEOCHEMICAL CYCLING

Major nutrient store in the watersheds are the organic-rich "soils", which are subject to a seasonal freeze/thaw cycle. A labile active layer exists for about 3 months of the year and leaching/erosion rates of this nutrient store should be very responsive to changes in temperature and precipitation in both depth and seasonal life time of the active layer.

In the coastal mixing zone between river and shelf waters the detrital suspended load settles out and, depending on availability of light, large phytoplankton blooms occur (Rusanov, et al, 1979). Essentially all of the organics produced are recycled in the salt wedge or on the bottom. The effect is to inject the river nutrients into the upper part of the halocline and thence into the regional circulation. During transgression and beach erosion the terrestrial nutrient store is mineralized and available for photosynthesis in the coastal zone. This source supports general shelf productivity independent of direct fluvial input. Nutrient availability in the open Arctic is affected by wind-driven mixing, ice-keel "ploughing" and shelf-edge breaking of internal waves in the halocline.

Codispoti et al., (1991) have suggested that changes in the areal extent of shelf could exert a significant influence on the productivity of the ocean due to related changes in the oceanic denitrification rate. Data suggest that approximately half of the present-day oceanic denitrification rate occurs in shallow and hemipelagic sediments. Therefore, the oceanic denitrification rate may decrease during glacial maxima when the global shelf area is reduced due to a lowering of sea level. Conversely, the rate may increase during higher stands of sea level. Thus changes in sea level introduce a potentially significant positive feedback mechanism into the "equation for global change". Lowered sea level during glacial periods allows higher primary production (because of a decrease in the removal rate of nitrate by denitrification) which may further cool the planet by allowing the biological pump to draw down atmospheric CO_2 levels. The cycle is reversed during warmer periods.

In the future, global warming/sea level rise will increase both the fluvial flux of nutrients from the active layer and the erosional flux from the transgression. The present strengths of both sources needs to be well characterized if productivity changes driven by global changes are to be predicted. Quantitative variations of carbon cycling components, primarily CO_2 cycling are largely depend on climatic variations (warming)and reduction of the ice cover. In turn, the increase in the output of CO_2 may contribute to further development of the greenhouse effect. Additional CO_2 may be entrapped by organic substances in the water and be transformed into sediment through the biological pump. This process depends on the intensity of biotic development associated with cycling of biogenic elements and changes in the composition of organic matter in the water. Anthropogenic input resulting from extensive oil and gas production would sharply increase the rate of organic-matter fluxes in the water and fluxes of CO_2 and CH_4 into the atmosphere, contributing to the build up of the greenhouse effect (Lyakhin and Rusanov, 1983).

Research priorities
1) Analysis of reservoirs and fluxes of CO_2, CH_4 and organic matter;
2) Assessment of the effects of altered climate and spatial-temporal change to biodiversity, biological productivity, and nutrient cycling in the coastal zone;
3) Paleoreconstruction of climatic change on the basis of obtained analytical data of molecular and isotopic composition of organic substances and;
4) Assessment of the fluxes including anthropogenic into the sediments and from sediments into the water masses and atmosphere by analysis of ecosystem structure and dynamics.

CRYOSPHERE

The broad Arctic shelf is particularly sensitive to physical changes associated with climate change. The broad shelves were significantly impacted by ice sheet growth and lowered sea level during glacial periods. Loss of the broad shelf areas would have a significant effect on the heat and salinity flux to the Arctic and the North Atlantic with the loci of sea-ice formation shifted to the Arctic Ocean and increased iceberg/meltwater flux.

The Holocene represents a period of considerable climatic variability despite the "stability" signal in the Greenland GISP core (Kotliakov et al, 1989; Barkov et al, 1992; Dansgaard et al., 1993). Important climatic elements with a high frequency such as Dansgaard/Oescheger and Heinrich events are probably controlled by oscillations of ice sheets and the North Atlantic variability/interaction with the Arctic Ocean (Bilodeau et al., 1995). The physical mechanism of these oscillations is unclear. Our understanding of sea ice response to such changes is poorly understood. Small changes in sea surface temperatures are significant to the formation and stability of sea ice (Zakharov, 1981). Understanding the relation between rapidly fluctuating climatic conditions and sea ice formation and extent will allow us to predict sea ice conditions in the future and the consequences of increased coastal erosion, and changes in the density structure of the Arctic Ocean and adjacent northern seas. In addition, such information will be useful for addressing economic issues associated with the shelf regions of the Arctic Ocean.

Permafrost is a particularly sensitive indicator of climate (Romanovsky, 1988, Pavlov, 1993). Some of the conditions affecting its formation are severe climate, sea-level change, glaciation, and geomorphologic changes as in Arctic deltas.

A main goal of current glaciological studies is to investigate the problem of how glaciers of the Arctic respond to climate changes and how these changes influence world ocean level. It is suggested it would be appropriate to focus efforts in key regions of the western Russian Arctic where changes in cryosphere and interaction of its components : (permafrost, glaciers and sea ice) are most dramatically pronounced (Are, 1988). The inflow of warm Atlantic water changing in time has a major effect on the Barents-Kara shelf and adjoining land. Evolution of cryosphere components can be investigated here in some key zones that are well known by geological and geophysical data and data obtained from drilling and thermometric and stationary observations.

Research Priorities

1) Identification of the periods of cooling and warming in different regions of the Arctic for the last 20,000 years as recorded in the glaciers of Arctic islands;
2) Estimate of the current state of Arctic glaciers to reveal anthropogenic impacts and climatic variability, and volume during last glacial maximum (20,000 years) and;
3) Volume, structure, dynamics and history of permafrost.

HUMAN-ENVIRONMENTAL INTERACTIONS AND RESPONSES TO PAST AND PRESENT ENVIRONMENTAL CHANGE

Over the past 20,000 years changes in the Arctic hydrologic cycle (sea level, river discharge, pack ice formation, etc.) forced by global changes in climate have occurred. These have had significant impacts on human and mammalian populations inhabiting the Russian Arctic. These changes appear to have permitted the human colonization of the Russian Arctic, Beringia, and ultimately the Americas. The transition from the Pleistocene to the Holocene introduced dramatic changes to the previously existing environments greatly effecting human adaptation in the Arctic. Changes in sea ice distribution and seasonality opened up new sustenance opportunities for early cultures as seen on Zhokhov Island around 8000 yr. B.P. Development of sea mammal hunting adaptations begins with open-water conditions. The development of thermokarst landscapes led to the expansion of whitefish and other coregonids. Stabilization of river systems permitted expansion of salmon fisheries into the Arctic basin.

In spite of the recency of the development of economic and social activities in the Arctic coastal zone, the scales and rates of these activities are increasing rapidly (Andreeva and Leksin, 1993, Slevich, 1977). Since it's initial history in the 15th and 16th centuries and particularly in the 20th century the Arctic coastal zone has become an important belt of industrial activity with marine ports, resource development, and numerous settlements all of which interact with the environment (Melnikov et.al., 1994, Andreeva, 1993). Predicting future impacts of climatic change on Arctic people is important; for instance extensive alterations of sea ice cover would have a huge impact on resident populations whether cooling or warming (Pavlenko, 1995).

Research Priorities-Past

1) Determination of the environmental changes or cultural adaptations which facilitated migrations of humans into and across northern Eurasia into the Americas;
2) Determination of the characteristic features of material culture of ancient man in the Arctic as related to both the environment and life sustenance systems;

3) Identification of characteristic features of climatic and vegetative evolution, and identification of boundaries and scale of glaciation of the Siberian Arctic and;
4) Identification of possible refugiums of megafauna in continental zones and relationship between economic activity of ancient man and extinction of relict megafauna.

Research priorities-Present/Future

1) Determination of human impacts which have influenced the natural development of the Russian Arctic ecosystem, including the 15th to 18th century settlements as well as earlier and later settlements; and if these developments had a wider impact;
2) Determination of cultural processes and strategies that, together with past data, may provide models for responding to future climatic, environment, or other global change;
3) Spacial variability of the coastal zone carrying capability relevant to human activity;
4) Vulnerability of human population to climate change socially, economically and for resource sustainability;
5) Use of traditional knowledge in utilization of renewable resources: historical experience and problems of its use in contemporary conditions and;
6) Models for management of social systems for sustainable development and ecological conflicts in utilizing renewable and nonrenewable resources and military activities in the Russian arctic.

REFERENCES CITED

Aagaard, K., J.H. Swift, and Carmack, E.C., 1985, Thermohaline circulation in the Arctic mediterranean seas: Jour. Geophys. Res., v. 94, p. 14,485-14,498.

Andreeva, E. and V. Leksin, 1993, Neotraditions in the Russian North, in Regional policy in Russia: editors: B. Prochorov and A.Pika, Center of Human Demography and Ecology, International Working Group on Indigenous People Association, Progress, Moscow 212 pp.

Andreeva, E.A., 1993, Ecological and legal problems of the Russian Arctic coastal zone economic development: Background paper for the Arctic State Commission Meeting, Moscow (available from author)

Antonov V.S., 1958, The run-off role in the Arctic Ocean Currents regime: Problemy Severa, v.1, p.52-64, in Russian.

Are F.E. , 1988, Thermal Abrasion of sea coasts: Polar Geography and Geology, v.12 (1) p. 1-157.

Atlas of the Arctic, 1985: "Gidrometizdat", pp.204.

Baskakov G.A. et al., 1987, Hydrological and ice conditions of the shelf zone of the Arctic Seas: In "Biological resources of the Arctic and Antarctic", M., "Nauka", p. 15-48, in Russian.

Barkov N.E., Bolshiyanov D.Yu. and others., 1992 ., New Data about Construction of the Vavilov Ice Cap in the Severnaya Zemlya Archipelago: Materialy glyaziologicheskikhissledovaniy. n 75, p. 35-41, in Russian.

Bilodeau, G., Hillaire-Marcel, C., de Vernal, A., and Vallieres, S., 1995, Environmental Changes related to Heinrich layers in Northwest North Atlantic: 5th International Conference on Paleoceanography, Dalhousie Univ., Halifax, N.S., p. 87.

Carmack, E.C., 1990, Large Scale Physical Oceanography of Polar Seas: in Polar Oceanography, Part A: Physical Science (ed. W.O. Smith), Academic Press, New York, p. 171-222.

Codispoti, L.A., Friederich, G.E., Sakamoto, C.M., and Gordon, L. I., 1991, Nutrient cycling and primary production in the marine system of the Arctic and Antarctic: Jour. Mar. Systems,

v. 2, p. 359-384.

Dansgaard, W., Johnsen, S.J., Clausen, H.B., Dahl-Jensen, D., Gundestrup, N.S., Hammer, C.U., Hvidberg, C.S., Steffensen, J.P., Sveinbjornsdottir, A.E., Jouzel, J., and Bond, G., 1993, Evidence for general instability of past climate from a 250-kyr ice-record: Nature, v. 364, p. 218-220.

Dvorkin, E.N., and Mustafin, N.V., 1977, Multiyear level flucuations of the seas of the Siberian shelf of the Arctic Ocean: Proceedings of the Arctic and Antarctic Research Institute v. 388, p. 132-134.

Gordeev, V.V., Martin, J.M., Sidorov, I.V., and Sidorova, M.V., 1996, A Reassessment of the Eurasian River input of water, sediment, major elements, and nutrients to the Arctic Ocean: Amer. Jour. of Sci., in press.

Ivanov V.V. 1976a, Fresh water balance of the Arctic Ocean: Proceedings of the Arctic and Antarctic Research Institute, v. 323, p.138-147, in Russian.

Ivanov V.V., 1976b, Mean annual overland flow in the Arctic: Proceedings of the Arctic and Antarctic Research Institute, v. 223, p.14-17, in Russian.

Ivanov V.V. 1994 Inflow of river water into the Arctic seas: Scientific conference on the Dynamics of the Arctic Climate. November, 7-10th, Goteborg, Sweden, p. H-4.

Kotliakov V., Korotkov I., Nikolaev V. and others., 1989, Paleoclimatic Reconstraction of the Holocene as the Result of Investigations, of Core from the Vavilov Ice Cap in the Severnaya Zemlya Archipelago: Materialy glyaziologicheskikh issledovaniy., V 67, p.103-108, in Russian.

Lyakhin, Yu. I, and Rusanov, V.P., 1983, Oxygen and carbon dioxide exchange between water and the atmosphere in the seas of the Arctic Ocean: Oceanology, v. 23(6), p. 963-969.

Melnikov E.S. and Pavlov, A.V., 1994, Experience of preliminary engineering-geocryological investigations in the oil and gas bearing regions: In: Proceedings of the 7th International Cold Regions Engineering Specialty Conference (eds. Smith, D. W. and Sego, D. C.) , Edmonton, Alberta, Canada, p. 793-799.

Midttun, L., 1985, Formation of dense bottom water in the Barents Sea: Deep-Sea res., v. 2, p. 1233-1241.

Nikiforov E.G. and Shpaikher A.O., 1980, Formation of a large-scale oscilations of the oceanographical regime of the Arctic Ocean: L., "Gidrometizdat", pp.270, in Russian.

Pavlenko, V.I., 1995, Problemy socialno-economicheskogo razvitija Arctici: M.: CNIINeftechim, 200 pp.

Pavlov A.V., 1993, Evolution of soil and ground thermal state in permafrost in connection with contmporary global changes of climate: In: Russian-American seminar on cryopedology and global change, 1992, Pushsino.

Romanovsky, N.N., 1988, Cryolithozone and zone of natural gas hydrates: problem of interrelation and interaction: Problems of geocryology, Nauka, Moscow, p. 35-40.

Rusanov, V.P. et al., 1979, Hydrochemical regime of the Arctic Ocean: L. Gidrometeoizdat, Proceedings of the Arctic and Antarctic Research Institute, v. 355, 144 pp.

Slevich, S.B., 1977, Shelf development usage: L. Gidrometeoizdat, p 46-70, in Russian.

The Climate Features: in : The Arctic and Southern Oceans., "Nauka", Leningrad, 1985, p.45-64, in Russian.

Zakharov V.F., 1981, Ice of the Arctic and the present day natural processes: L., Godrometeoizdat, 96 pp.

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